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This report presents results of a study to develop background information necessary for the accurate assessment of hydrocarbon emissions from ship and barge loading and unloading of gasoline and crude oil. The report assesses marine terminal facilities, marine terminal operations, cruise history and product movement statistics, hydrocarbon emission rates and characteristics, control technology state of the art, safety considerations of marine terminal control technology and economics of controlling marine terminal emissions. The report also includes the results of a detailed cost analysis for a refrigeration and an absorption marine terminal vapor recovery system. Data gathering activities focused on the Houston-Galveston area; however, information was also assembled on hydrocarbon emissions from marine terminal operations in the metropolitan Los Angeles area generated by handling of gasoline and crude oils, including Alaskan north slope crude.

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BACKGROUND INFORMATION ON HYDROCARBON EMISSIONS FROM MARINE TERMINAL OPERATIONS

VOLUME II: APPENDICES

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VOLUME II: APPENDICES

by

C.E. Burklin, J.D. Colley, and M.L. Owen

Radian Corporation
8500 Shoal Creek Blvd.
P.O. Box 9948
Austin, Texas 78766

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APPENDIX I

VESSELS TRANSPORTING CRUDE OIL AND GASOLINE IN THE HOUSTON-GALVESTON AREA

VESSELS TRANSPORTING CRUDE OIL AND GASOLINE IN THE HOUSTON-GALVESTON AREA

Appendix I contains information supplied by owners of the larger marine terminals in the Houston-Galveston area concerning the marine tankers which visited their docks to transfer crude oil or gasoline. The responses were not consistent in the type of information presented. Data on vessel names, DWT, ownership, service, quantity loaded in 1975, number of cargo tanks, and number of visits in 1975 were obtained in different responses. Very little information was obtained on the specific barges that transferred gasoline and crude oil in 1975 in the Houston-Galveston area.

TABLE I-1

SHIPS UNLOADING CRUDE OIL AT EXXON'S BAYTOWN REFINERY IN 1975

Vessel Name	DWT	Ownership
Alchiba	28,315	Foreign
Argolis	53,520	Foreign
Buckeye	46,194	Foreign
Carcape	76,996	Foreign
Capetan Mathios	30,200	Foreign
Capto	62,150	Foreign
Caspain Trader	75,669	Foreign
Carolyn Jane	NA	NA
Ekaterini	69,119	Foreign
Esso Torino	70,324	Foreign
Esso Stuttgart	50,420	Foreign
Esso Lorraine	51,628	Foreign
Esso Phillipines	69,742	Foreign
Esso Puerto Rico	33,581	Foreign
Esso Antwerp	76,209	Foreign
Esso Bremen	50,900	Foreign
Esso Koln	50,640	Foreign
Esso Karachi	20,987	Foreign
Esso Albany	22,367	Foreign
Esso Lincoln	50,769	Foreign
Esso Stockholm	52,425	Foreign
Esso Everett	NA	Foreign
Esso Roma	37,698	Foreign
Esso Brasilia	38,154	Foreign
Esso Milano	70,310	Foreign
Esso Castellon	76,290	Foreign
Esso Mukaishima	22,500	Foreign
Esso Coral Bagles	NA	Foreign
Esso Guam	22,360	Foreign

TABLE I-1 (Continued)
SHIPS UNLOADING CRUDE OIL AT EXXON'S BAYTOWN REFINERY IN 1975

Vessel Name	DWT	Ownership
Exxon Baltimore	51,926	Exxon
Exxon Lexington	40,910	Exxon
Exxon Jamestown	40,872	Exxon
Exxon Philadelphia	75,649	Exxon
Farah Pahlavi	56,800	Foreign
FFM Matarangi	38,200	Foreign
Global Hope	38,275	Foreign
Gherania	58,543	Foreign
Gherestos	62,281	Foreign
Grete Maersk	31,500	Foreign
George Vergottis	59,412	Foreign
King Cadmus	56,023	Foreign
Mostun Sanko	70,983	Foreign
Manhattan Baron	NA	NA
Olympic Glory	77,874	Foreign
Onoha	52,600	Foreign
Romelia	34,300	Foreign
Tamarita	74,883	Foreign
Slavisa Vajner	69,874	Foreign
Vasiliki	69,119	Foreign
World Beauty	49,751	Foreign

NA - Not Available

TABLE I-2

SHIPS LOADING GASOLINE AT EXXON'S BAYTOWN REFINERY IN 1975

Vessel Name	Service	Ownership
Exxon Bangor	Multiple	Exxon
Exxon Baton Route	Multiple	Exxon
Exxon Boston	Multiple	Exxon
Exxon Gettysburg	Multiple	Exxon
Exxon Houston	Multiple	Exxon
Exxon New Orleans	Multiple	Exxon
Exxon Philadelphia	Multiple	Exxon
Exxon San Francisco	Multiple	Exxon
Exxon Chester	Multiple	Exxon
Exxon Jamestown	Multiple	Exxon
American Trader	Multiple	American Charter
Anja	Multiple	American Charter
Bald Butte	Dedicated	American Charter
Sealift Atlantic	Multiple	American Charter
Sealift Mediterranean	Dedicated	American Charter
Shenandoah	Dedicated	American Charter
Sealift Caribbean	Dedicated	American Charter
William J. Fields	Multiple	American Charter
Tampico	Multiple	American Charter
Eagle Transporter	Multiple	American Charter
Wilke	Multiple	American Charter
Hess Voyager	Multiple	Hess Shipping Co.
Gulf Solar	Dedicated	Blackships, Inc.
Mobil Aero	Multiple	Mobil Oil Corp.
Texaco Florida	Dedicated	Texaco, Inc.
Texaco California	Dedicated	Texaco, Inc.
Texaco Maryland	Multiple	Domestic Tankers
Shoshone	Dedicated	Military Sealift Command

TABLE I-2 (Continued)
SHIPS LOADING GASOLINE AT EXXON'S BAYTOWN REFINERY IN 1975

Vessel Name	Service	Ownership
Millicoma	Dedicated	Military Sealift Command
USNS Yukon	Multiple	Military Sealift Command
Sealift Arctic	Dedicated	Military Sealift Command
Sealift Indian Ocean	Multiple	Military Sealift Command

TABLE I-3
SHIPS LOADING CRUDE OIL AT EXXON'S BAYTOWN REFINERY IN 1975

Vessel Name	Ownership	Quantity Loaded (10^3bbl)
Exxon Baltimore	Exxon	1,457.3
Exxon Jamestown	Exxon	835.1
Exxon Lexington	Exxon	1,447.8
Exxon Philadelphia	Exxon	3,120.1

TABLE I-4
SHIPS LOADING GASOLINE AT SHELL'S DEER PARK REFINERY IN 1975

Vessel Name	Gross Capacity (10^3bbls)	Number of Cargo Tanks
Key Tanker	156	33
Perryville	204	27
Tullahoma	207	27
Colorado	260	30
Pasadena	230	24
Seabulk Challenger	320	18
Valley Forge	322	27

TABLE I-5
TYPICAL SHIPS CHARTERED BY SHELL FOR DELIVERING CRUDE OIL TO DEER PARK

Vessel Name	DWT	Number of Cargo Tanks	Ownership
Oliva	55,000	21	German
Michael Carras	59,000	33	Greek
Helfrid Billner	47,000	15	Swedish

TABLE I-6
SHIPS LOADING GASOLINE AT AMOCO'S TEXAS CITY REFINERY IN 1975

Vessel Name	Ownership	Number of Visits At Texas City in 1975
AMOCO Delaware	AMOCO	20
AMOCO Connecticut	AMOCO	20
AMOCO Virginia	AMOCO	7
Mobile Gas	Mobil	1
Mobile Fuel	Mobil	1
Mobil Power	Mobil	1
Hess Petrol	Amerada Hess	3
Hess Voyager	Amerada Hess	2
E.M. Quenny	Keystone Shipping	3
American Eagle	American Foreign Steamship	1
Exxon Florance	Exxon	11
Trinity	NA	2
F. Hoskins	NA	1
LaGetty	NA	2
Corsair	NA	2
TOTAL		77

NA - Not Available

TABLE I-7

SHIPS UNLOADING CRUDE OIL AT AMOCO'S TEXAS CITY REFINERY IN 1975

Vessel Name	Ownership	Number of Visits to AMOCO Texas City
Kini	Foreign	9
Maria	Foreign	8
Pella	Foreign	2
Baraolla	Foreign	1
Adreana Fassio	Foreign	1
Thomas Q	Foreign	1
Verconella	Foreign	1
Donold	Foreign	3
Perikem	Foreign	1
Persepolis	Foreign	4
Crinis	Foreign	2
Conqueror	Foreign	7
Exxon Munchen	Exxon	1
Alvega	Foreign	9
Alkes	Foreign	6
Exxon Ghent	Exxon	1
Tamba Mara	Foreign	4
Triposis	Foreign	4
Varanger	Foreign	1
Tasso	Foreign	2
Desert Song	Foreign	4
Ocean Challenger	Foreign	1
Sally II	Foreign	2
Petro Pan	Foreign	1
Attica	Foreign	1
Texaco Alaska	Texaco	2

TABLE I-7 (Continued)
SHIPS UNLOADING CRUDE OIL AT AMOCO'S TEXAS CITY REFINERY IN 1975

Vessel Name	Ownership	Number of Visits to AMOCO Texas City
Dauntless Colocotronas	Foreign	2
Fearless Colocothronas	Foreign	2
St. Thomas	Foreign	2
Cosmonaftis	Foreign	2
AMOCO Yorktown	AMOCO	2

TABLE I-8
OCEAN BARGES LOADING GASOLINE AT AMOCO TEXAS CITY IN 1975

Vessel Name	Ownership	Number of Visits to AMOCO Texas City
Esther Moran	Moran Towing Co.	32
Clipper	NA	1
M. Ingram	Ingram Barge Co.	1

NA - Not Available

TABLE I-9
INTERCOASTAL BARGES WHICH LOADED GASOLINE AT AMOCO'S TEXAS CITY TERMINAL

Vessel Name	Ownership	Number of Visits to AMOCO Texas City
Duncan L. Hines	Hines, Inc.	10
James R. Hines	Hines, Inc.	29
Thomas W. Hines	Hines, Inc.	6
Billy Waxler	Waxler Towing	14
Ray Waxler	Waxler Towing	10
Achilles	Sabine Towing	1
Apollo	Sabine Towing	1
Atlas	Sabine Towing	14
Poseidon	Sabine Towing	28
Zephyr	Sabine Towing	12
Lady Kimberly	Inland Oil & Trans.	1
Lady Linda	Inland Oil & Trans.	7
Lady Patricia	Inland Oil & Trans.	2
Exxon Baytown	Exxon	13
Exxon Bayport	Exxon	1
Exxon Brownsville	Exxon	3

TABLE I-10

SHIPS LOADING GASOLINE AT ARCO'S HOUSTON REFINERY IN 1975

Vessel Name	ARCO or Company Charter	Time or Trip Charter	Not Controlled By ARCO
Atlantic Prestige	✓		
Atlantic Heritage	✓		
Atlantic Enterprise	✓		
Edgar M. Queeny		✓	
Monmouth		✓	
Phillips Washington			✓
Texaco Illinois			✓
Texaco Montano			✓

TABLE I-11

BARGES LOADING GASOLINE AT ARCO'S HOUSTON REFINERY IN 1975

Vessel Name	ARCO or Company Charter	Time or Trip Charter	Not Controlled By ARCO
GDM-60			✓
Exxon 119			✓
Ellis 2003			✓
Petrochem	✓		
REB 2202		✓	
AD 315		✓	
T10-500		✓	
Patco 507			✓
SMT 416		✓	

TABLE I-12

SHIPS UNLOADING CRUDE OIL AT ARCO'S HOUSTON REFINERY IN 1975

Vessel Name	ARCO or Company Charter	Time or Trip Charter	Not Controlled By ARCO
Kenai Peninsula	✓		
Clairhall		✓	
Ibeaux			✓
El Steininger	✓		
Atlantic Challenger	✓		
Vardis V			✓
Capetan Mathios		✓	
Esso Jamestown			✓
Esso New Haven			✓
Apollonian Wave		✓	
Grigorousa			✓
Esso Karachi			✓
Tassos			✓
Romelia			✓
St. Thomas			✓
Mikton		✓	
World Promise			✓
Zaria		✓	
Afran Neptune		✓	
Llangorse			✓
Coranado		✓	
Albisola		✓	
Lady Clio		✓	
Cepheus		✓	

APPENDIX II

VAPOR CONTROL SYSTEM COST DATA

VAPOR CONTROL SYSTEM COST DATA

The cost data presented in Appendix II represent "best estimates" and are based upon the best cost information available. There are no marine loading vapor control systems currently in use for gasoline transfers from which to draw cost information. Although tanktruck loading emission control systems are in operation, they are much smaller and are designed to cope with a different set of problems.

EXXON COMPANY

System Information

System: Refrigeration
Size: 50,000 bbl/hr

Shoreside Costs

Ship to shore connection	$1,920,000
Vapor collection system	$2,280,000
Installed vapor recovery unit	$4,030,000
Off sites	$1,460,000
	$9,690,000

Vessel Modification Costs

Ship	$350,000/ship
Barge	$ 85,000/barge

All Exxon Vessels $4,000,000

Operating Costs (annual) (shoreside)	35×10^6 bbl/yr
Depreciation	$1,607,000
Labor	$ 393,000
Maintenance	$ 260,000
Utilities	$ 30,000
Overhead	$ 331,000
Taxes	$ 170,000
	$2,791,000

Operating Costs (annual) (Continued)
(vessel)

Depreciation	$ 424,000
Retrofitting	$ 147,000
Maintenance	$ 343,000
Loading Delay	$ 750,000
	$1,664,000
Recovered product credit	$ 134,000
Total	$4,321,000/yr

Reference 13

AMOCO OIL COMPANY

System Information

System: Refrigeration
Size: 18,000 bbl/hr

Shoreside Costs

Labor	$1,360,000
Contengencies	$ 325,000
Engineering	$ 300,000
Dock platforms	$1,200,000
Piping & Supports	$ 500,000
Water seals	$ 150,000
Vapor hoses	$ 45,000
Instrumentation	$ 90,000
Pressure storage system	$ 30,000
Vapor recovery unit	$1,000,000
	$5,000,000

Ship Modification Costs

3 ships at 300,000	$ 900,000
35 barges at 50,000	$1,750,000
1 ocean barge	$ 150,000
	$2,800,000

Operating Costs (annual)	20×10^5 bbl/yr
Electric power	$ 64,000
Labor	$ 35,000
Maintenance	$ 200,000
Chemicals	$ 1,000
Recovered product credit	$ -75,000
	$ 225,000

Reference 4

ARCO

System Information

System: Refrigeration
Size: 16,000 bbl/hr

Shoreside Costs

Vapor collection system	$2,400,000
Installed vapor recovery unit	$2,100,000
Off-sites	$1,200,000
	$5,700,000

Ship Modification Costs

Modification of two ships	$ 300,000

Reference 6

EDWARDS ENGINEERING

System Information

System: Refrigeration
Size: 20,000 bbl/hr

Shoreside Costs

Vapor collection system	$ 200,000
Installed vapor recovery unit	$ 700,000

Reference 10

MARATHON OIL COMPANY

System Information

System: Absorption
Size: 30,000 bbl/hr

Shoreside Costs

Vapor collection system	$ 450,000
Installed vapor recovery unit	$ 850,000
	$1,300,000

Reference 15

SHELL OIL COMPANY

System Information

System: Absorption
Size: 25,000 bbl/hr

Shoreside Costs

Onsite Capital	$2,000,000
Offsite Capital	$2,500,000
Non-capital Expense	500,000
	$5,000,000

Ship Modification Costs

Cost for 7 vessels	$800,000 to $1,200,000

Operating Costs

Electricity	$ 36,000
Water (supply & waste treatment)	$ 12,000
Fuel	$ 92,000
	$ 140,000

Reference 18

APPENDIX III

RESULTS FROM INDUSTRY TEST PROGRAMS

RESULTS FROM INDUSTRY TEST PROGRAMS

The tables and figures presented in Appendix III summarize the emission test data collected by the petroleum industry concerning hydrocarbon emissions from marine terminal operations. Test data collected by the petroleum industry are presented in Appendix IV.

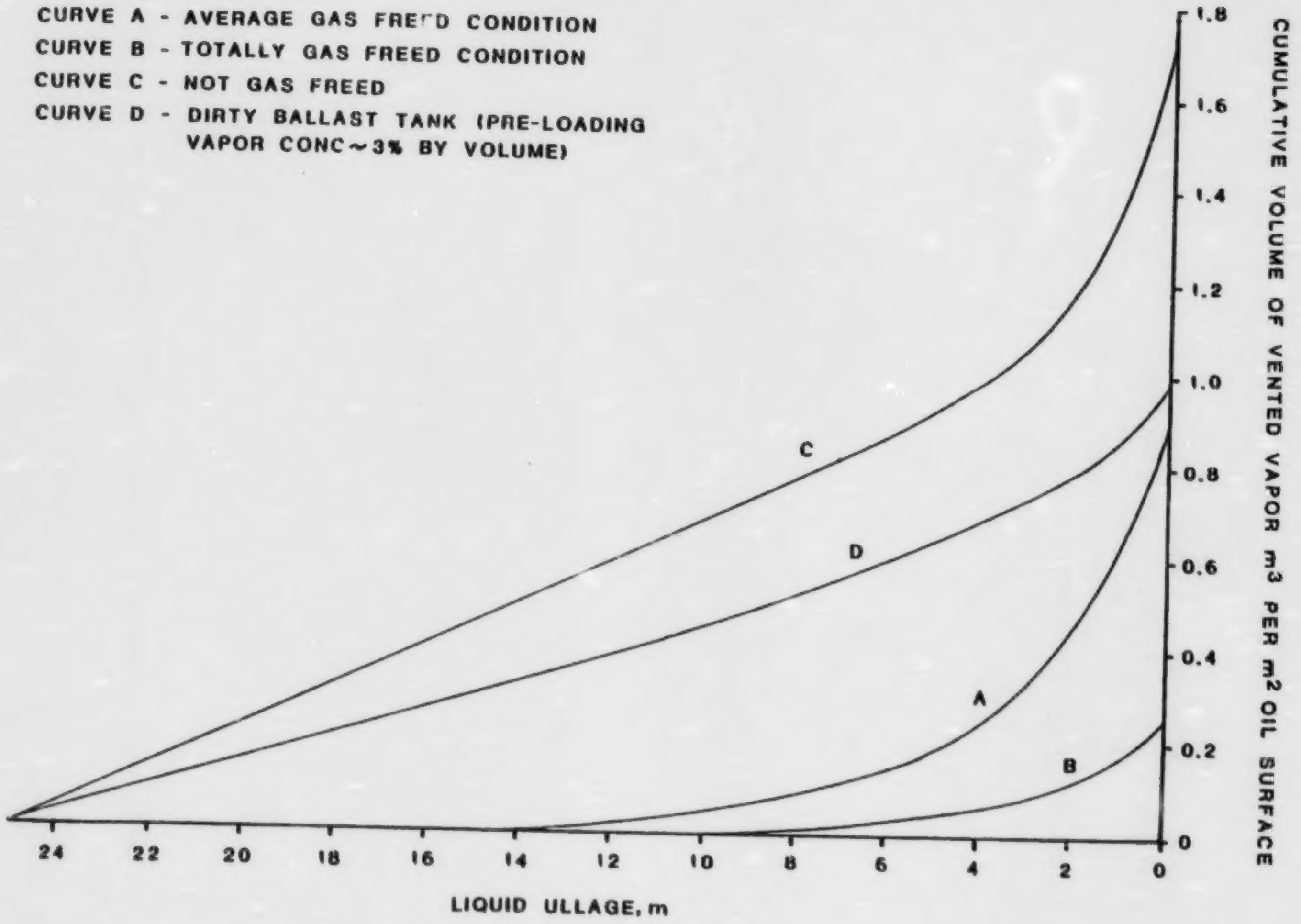


FIGURE III-1 B.P. TEST DATA
HYDROCARBON EMISSIONS FROM LOADING A 215,000 DWT TANKER

REFERENCE 7

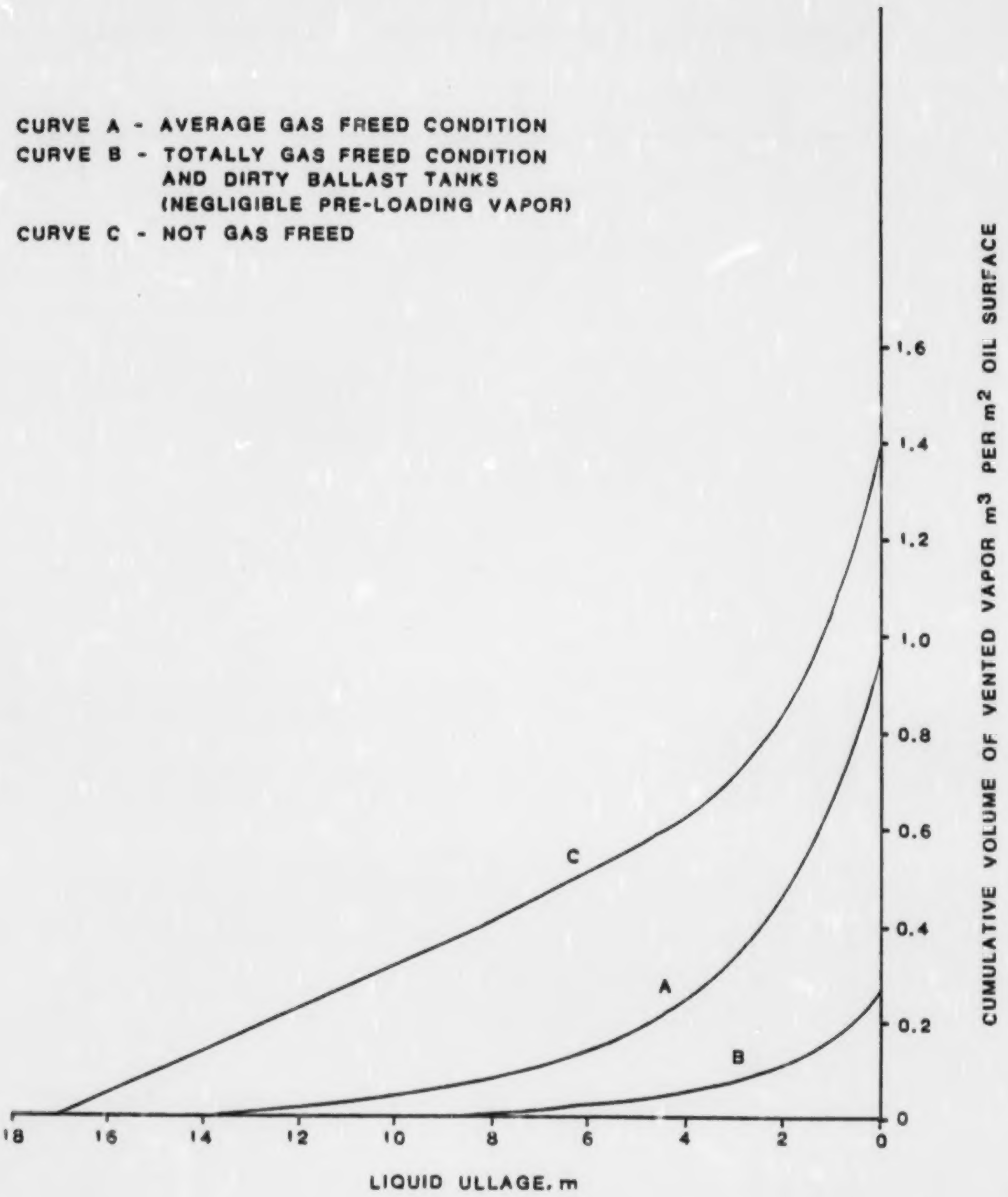


FIGURE III-2 B.P. TEST DATA
HYDROCARBON EMISSIONS FROM LOADING A 54,000 DWT CRUDE TANKER

FERENCE 7

TABLE III-1

AMOCO GASOLINE LOADING TEST RESULTS

PERCENT GASOLINE VAPOR IN AIR EMITTED FROM TANKERS DURING LOADING

Ship	Date (1974)	Port	Previous Cargo	Ambient Temp	RVP Present Cargo	% Vapor in Air Compartment		
						Empty	Half Full	Almost Full
Wisconsin	2/26	W	Gasoline	41	--	9		
Wisconsin	2/26	W	Half Ballast	41	--	14		
Wisconsin	3/14	W	Gasoline	46	--	6	6.5	24
Delaware	3/26	TC	Gasoline	57	11	7		
Delaware	3/26	TC	Half Ballast	57	11	4		
Connecticut	March	TC	Gasoline	82	10.5	4	9.4	27
Connecticut	3/9	TC	Ballast	70	11.5	1.1		
Virginia	3/13	TC	Gasoline	66	13.5	0	.5	
Delaware	4/8	TC	Gasoline Butterworth	77	11	2.8	3.4	4.6
Wisconsin	5/31	W	Gasoline	67		19	19	64
Virginia	6/5	TC	Gasoline	86	11.3	1.2	2.9	6.8
Wilm. Getty	6/26	TC	Gasoline	78		7.4	7.4	25
Connecticut	8/2	TC	Gasoline	80	11		11.4	40
Indiana	8/13	W	Gasoline	68			7	47
Barge St 132	8/13	TC	--	--	9.2		1.2	50

Reference 4

TABLE III-2

ATLANTIC RICHFIELD COMPANY

VARIOUS EMISSION EFFECTS RATED ACCORDING TO EMISSION MAGNITUDE

Group	Lifting/Compartments	Comment	Average Emission Factor lb/1000 gal	Average Percent Hydrocarbons Volume
A	1./7C, 5P	Fast Loading, Low TVP, Clean Compartments	0.40	2.1
B	3./1C, 4C, 7C, 11C	Fast Loading, Medium TVP Clean Compartments	0.52	2.6
C	2./1S, 9S	Slow Loading, High TVP Clean Compartments	0.92	4.2
D	2./5S, 7S, 8S	Slow Loading, High TVP, Partially Clean Compartments	1.51	6.9

Reference 6

TABLE III-3
SHELL OIL TEST DATA
MARINE LOADING VAPOR EMISSIONS (MOTOR GASOLINES)
DEER PARK, TEXAS

Test No.	1	2	3	4	5
Ship	Valley Forge	Valley Forge	Valley Forge	Valley Forge	Valley Forge
Compartment Sampled	6S	4S	1C	6S	1S
Month	Oct.	Oct.	Oct.	Oct.	Nov.
RVP (PSI)	12.0	12.0	13.5	12.0	13.3
Temperature(°F)	77	79	77	75	54
True Vapor Pressure (PSI)	8.6	8.9	9.7	8.3	6.3
Previous Cargo	Gasoline	Gasoline	Gasoline	Gasoline	Gasoline
Compartment Capacity (bbls @ 98% Full)	15,485	11,653	33,264	15,485	13,020
Cleaning Method	a	a	a	a	None
Initial HC Concentration	1.1%	0.1%	0.9%	4.3%	8.2%
Emitted Hydrocarbons					
Max. Concentration	67.4%	59.2%	65.3%	50.1%	59.5%
Avg. Concentration	6.3%	6.9%	7.0%	8.3%	16.6%
Avg. Molecular Wt.	64	65	63	67	61
Lb/1000 Gallons Loaded	1.38	1.52	1.50	1.90	3.61
Tons HC/Ton Loaded (Assuming 6 lb/gallon)	.00023	0.00025	.00025	.00032	.00060

a = hand hosing for 20 minutes

Reference 19

TABLE III-4

EXXON TEST DATA

HYDROCARBON EMISSIONS FROM TANKERS AND BARGES DURING MOTOR GASOLINE LOADING AT BAYTOWN (1975)

Vessel	Tank Condition	Volume % Hydrocarbon	Volume % Loaded Into Vessel and Tank Type	Weighted Average % Hydrocarbon (As Butane)	Annual Amount* Loaded, $\overline{M}$ Gal	Annual Emission, $\overline{M}$ Lb	Emission Factor (Lb/1,000 Gal)
Tanker	Effectively Gas-Freed	3.24	50.4	6.43	1,134** (81.3%)	1.67+	1.47
	Ballasted	6.96	8.8				
	Empty, Not Cleaned	10.26	40.8				
Barge (Port Everglades)	Effectively Gas-Freed	5.69	11.2	11.71	146** (10.5%)	0.39+	2.66
	Ballasted	9.08	32.3				
	Empty, Not Cleaned	14.40	56.5				
Barge	Empty, Not Cleaned	18.35	100.0	18.35	114** (8.2%)	0.48+	4.14

Total = 2.54

* Numbers in parentheses = volume % of total 1975 motor gasoline marine loading; $\overline{M}$ = 1,000,000.

** Average 1972, 1973, and 1974 loadings:

Tanker loadings = 1,198 $\overline{M}$ gallons (82.3%).
Port Everglades loadings = 188 $\overline{M}$ gallons (12.9%).
Other barge loadings = 70 $\overline{M}$ gallons (4.8%).

+ Average 1972, 1973, and 1974 emissions:

Tanker emissions = 1.76 $\overline{M}$ pounds/year.
Port Everglades emissions = 0.50 $\overline{M}$ pounds/year.
Other barge emissions = 0.29 $\overline{M}$ pounds/year.
Total = 2.55 $\overline{M}$ pounds/year.

Reference 13

TABLE III-5

EXXON TEST DATA

HYDROCARBON EMISSIONS FROM TANKERS AND BARGES DURING AVIATION GASOLINE LOADING AT BAYTOWN (1975)

Vessel	Tank Condition	Volume % Hydrocarbon	Volume % Loaded Into Vessel and Tank Type	Weighted Average % Hydrocarbon (As Butane)	Annual Amount* Loaded, $\overline{M}$ Gal	Annual Emission, $\overline{M}$ Lb	Emission Factor (Lb/1,000 Gal)
Exxon Tanker	Effectively Gas-Freed	1.63	50.2	5.35	22.7** (40.5%)	0.027+	1.47
	Empty, Uncleaned; Previous Cargo: Avgas	6.66	19.2				
	Empty, Uncleaned: Previous Cargo: Mogas	10.64	30.6				
Other Tanker++	Effectively Gas-Freed	1.63	50.2	4.13	21.1** (37.6%)	0.020+	1.13
	Empty, Uncleaned; Previous Cargo: Avgas	6.66	49.8				
Barge	Empty, Uncleaned; Previous Cargo: Mogas	18.35***	100.0	18.35	12.3** (21.9%)	0.052+	4.25

Total = 0.099 = 0.10

* Numbers in parentheses = volume % of total 1975 aviation gasoline marine loading; $\overline{M}$ = 1,000,000.

** Average 1972, 1973, and 1974 loadings:
Exxon Tanker Loadings = 23 $\overline{M}$ gallons (36.5%).
Other Tanker Loadings = 33 $\overline{M}$ gallons (52.4%).
Barge Loadings = 7 $\overline{M}$ gallons (11.1%).

*** Barge assumed same as motor gasoline.

+ Average 1972, 1973, and 1974 emissions:
Exxon Tanker Emissions = 0.03
Other Tanker Emissions = 0.04
Barge Emissions = 0.03
Total = 0.10

++ "Other Tanker" category represents tankers owned or leased by the Military Sealift Command to transport primarily jet fuel and aviation gasoline.

Reference 13

TABLE III-6

EXXON LOADING EMISSION CORRELATION

$$E = \left[\frac{C \cdot V}{100}\right] + \left[P \cdot A \cdot (G-U)\right]$$

where:

E is the total volume of pure HC emitted in ft^3 at the loading conditions,

C is the appropriate arrival HC concentration (%) selected from the table below

V is the volume of cargo loaded in ft^3,

P is the true vapor pressure (TVP) of the cargo in psia,

A is the surface area of the cargo in ft^2,

G is the HC generation coefficient value of 0.36 $ft^3/(ft^2 \cdot psia)$,

U is the final true ullage correction in $ft^3/(ft^2 \cdot psia)$, from Figure III-3.

The Exxon correlation is based principally upon gasoline loading data.

Cargo Tank Arrival Condition Category	Average Arrival HC Concentration (Vol %)	Range of Arrival HC Concentration (Vol
Cleaned	2.5	0 - 5.0
Dirty	5.0	2.0 - 8.0
Empty and Undisturbed	8.0	2.5 - 13.5

Reference 12

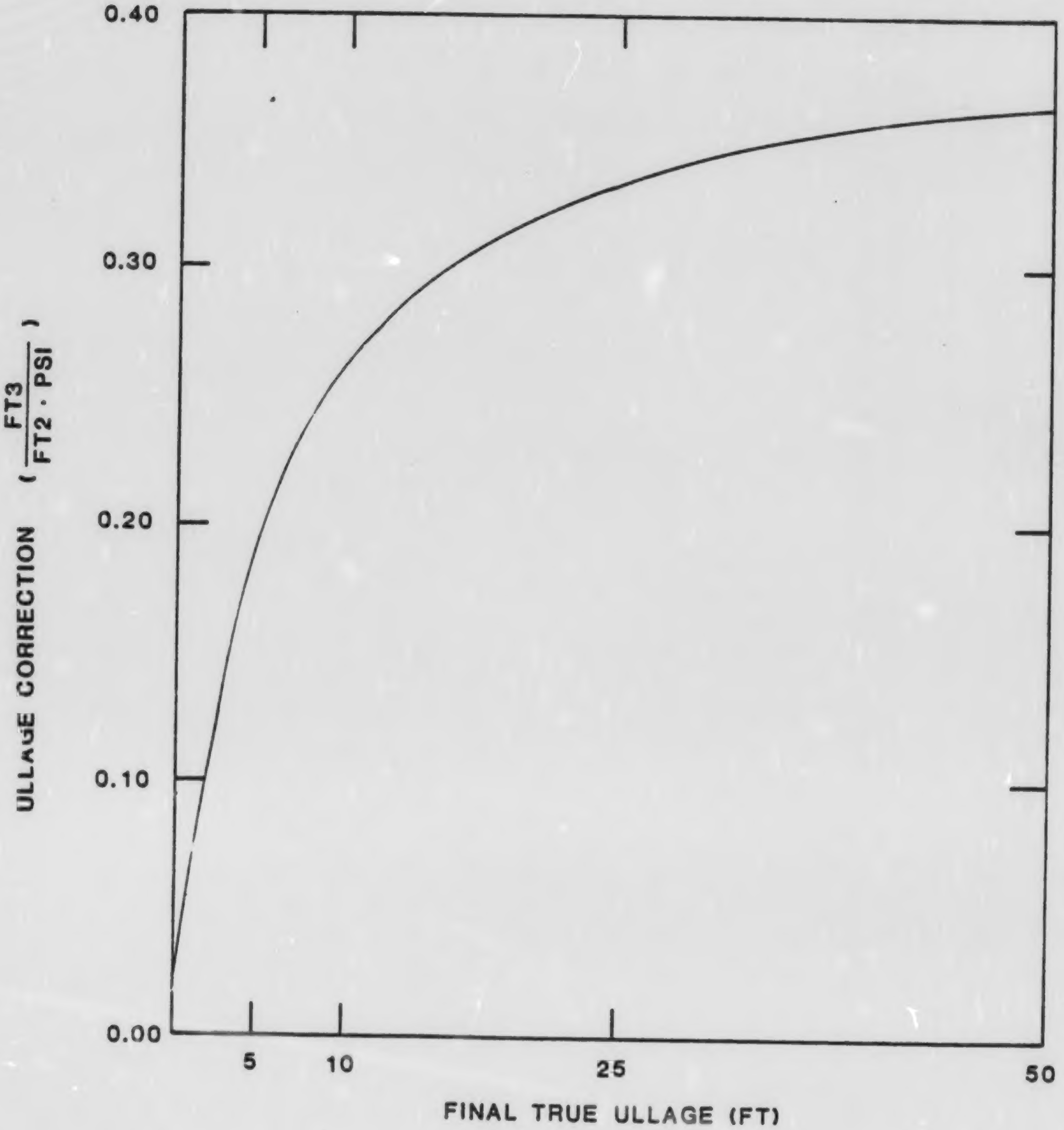


FIGURE III-3 HYDROCARBON GENERATION COEFFICIENT, FINAL ULLAGE CORRECTION TO THE EXXON CORRELATION

FERENCE 13

TABLE III-7

WOGA TEST PROGRAM
CALCULATED HYDROCARBON EMISSION VALUES
CRUDE OIL LOADING TEST, 5-8-76,
AVILA TERMINAL, TANKER: LION OF CALIFORNIA

Cargo Tank	Gallons Oil Loaded	Total Vapor Vented, SCF	Volume Hydrocarbon	Hydrocarbon Vented, SCF	Molecular Weight of HC	HC Emission Lb/1000 Gal.
3P	164,262	21,811	3.4	742	53.5	0.64
3S	164,262	21,640	3.8	822	57.5	0.76
7P	157,080	20,850	2.1	438	55.3	0.40
7S	157,080	20,714	2.1	435	63.1	0.46
Wing Tanks	642,684	85,015	2.9	2437	56.9	0.57
3C	365,652	47,989	5.3	2543	70.3	1.28
7C-OVA	354,732	46,562	5.9	2747	62.3	1.27
Center Tanks	720,384	94,551	5.6	5290	66.1	1.23
Centers and Wings	1,363,068	179,556	4.3	7727	63.2	0.94
3C	365,652	47,989	5.3	2543	70.3	1.28
7C-Gascope	354,732	46,562	7.4	3446	62.3	1.60
Center Tanks	720,384	94,551	6.3	5989	65.7	1.44
Centers and Wings	1,363,068	179,556	4.7	8426	63.2	1.03

Reference 22

TABLE III-8

AMOCO TEST RESULTS

RESIDUAL HYDROCARBON CONCENTRATIONS IN UNLOADED CRUDE BARGES

Crude	High Island	Point Comfort	Johnson Bayou	Forked Island	Trinidad	Sun-B	Zueitona	Empire	Essider
Gravity	31.6°	39.4°	46.4°	46.6°	33.1°	43.1°	40.5°	30.4°	36.2°
RVP	1.7	3.7	5.5	6.8	2.4	4.2	4.8	3.0	7.3
Deck Temp.	82°F	86°F	84°F	84°F	86°F	88°F	88°F	91°F	82°F
Half-Way Down									
C_1	-	1.4	3.3	4.8	2.5	.9	.9	1.4	.7
C_2	.1	.5	2.6	5.1	1.0	.8	.4	.3	.2
C_3	.1	.7	2.7	5.8	.7	.9	.7	.5	.5
iC_4	trace	.3	.8	2.1	.2	.3	.2	.2	-
nC_4	-	.3	.7	1.8	.2	.4	.6	.3	.3
C_5+	-	.7	1.2	3.0	-	.9	.7	.3	.2
CO_2	.1	-	.2	.4	.2	.1	.2	-	-
Inert	.9	.9	.8	.7	.9	.9	1.1	.9	.9
Total HC	.2	3.9	11.3	22.6	4.6	4.2	3.5	3.0	1.9
N_2	77.9	75.1	69.1	60.2	74.4	74.8	75.3	75.7	76.6
O_2	20.9	20.1	18.6	16.1	19.9	20.0	20.1	20.4	20.6
6" Off Bottom									
C_1	-	2.7	6.8	7.0	4.0	4.5	1.6	2.8	1.7
C_2	1.0	2.5	9.3	9.9	3.3	5.4	2.0	1.3	3.2
C_3	1.7	4.6	11.4	12.1	3.6	8.6	5.2	2.5	8.0
iC_4	1.0	2.8	3.9	4.6	1.3	3.4	2.0	1.0	2.5
nC_4	1.2	2.6	3.6	3.9	1.5	3.7	4.4	1.7	5.4
C_5+	2.7	3.3	4.6	5.0	1.8	4.2	5.0	2.0	4.0
CO_2	-	-	.4	.6	.6	.4	.3	-	-
Inert	.9	.8	.6	.5	.8	.7	1.1	.8	.7
Total HC	8.8	18.5	39.6	42.5	15.5	29.8	20.2	11.3	24.8
N_2	71.1	63.6	46.9	44.5	65.5	54.5	62.1	69.2	58.7
O_2	19.1	17.1	12.5	11.9	17.6	14.6	16.6	18.7	15.8

Reference 2

APPENDIX IV

INDUSTRY TEST DATA

AMOCO
ARCO
EXXON
SHELL

INDUSTRY TEST DATA

Appendix IV presents a cross section of the test data collected by the petroleum industry concerning hydrocarbon emissions from marine terminal operations. The test data were supplied by Arco, Amoco, Exxon, and Shell.

AMOCO TEST RESULTS

(Reference 3)

VAPOR BLANKET HEIGHT vs DEPTH OF FILL

AMOCO ILLINOIS – NOV.6,1974
WHITING, INDIANA
NORMAL FILLING RATE – FIRST FOOT 3–4 MINUTES
AMBIENT TEMP. 55° – VAPOR TEMP. 73°

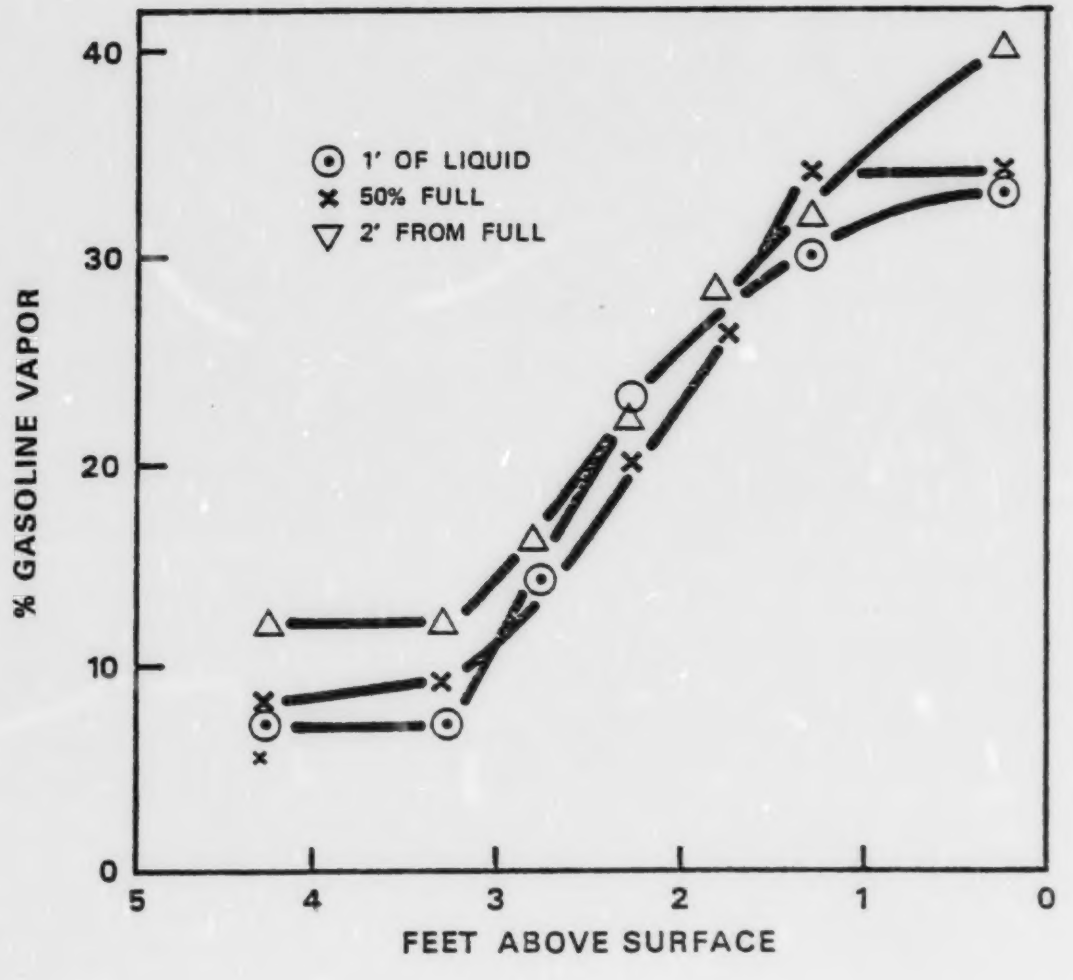


FIGURE 1

VAPOR BLANKET HEIGHT vs DEPTH OF FILL

AMOCO ILLINOIS – NOV.6,1974
WHITING, INDIANA
SLOW INITIAL FILL – 1 FOOT IN 20 MINUTES
THEN NORMAL FILL RATE
AMBIENT TEMP. 55 – VAPOR TEMP. 62

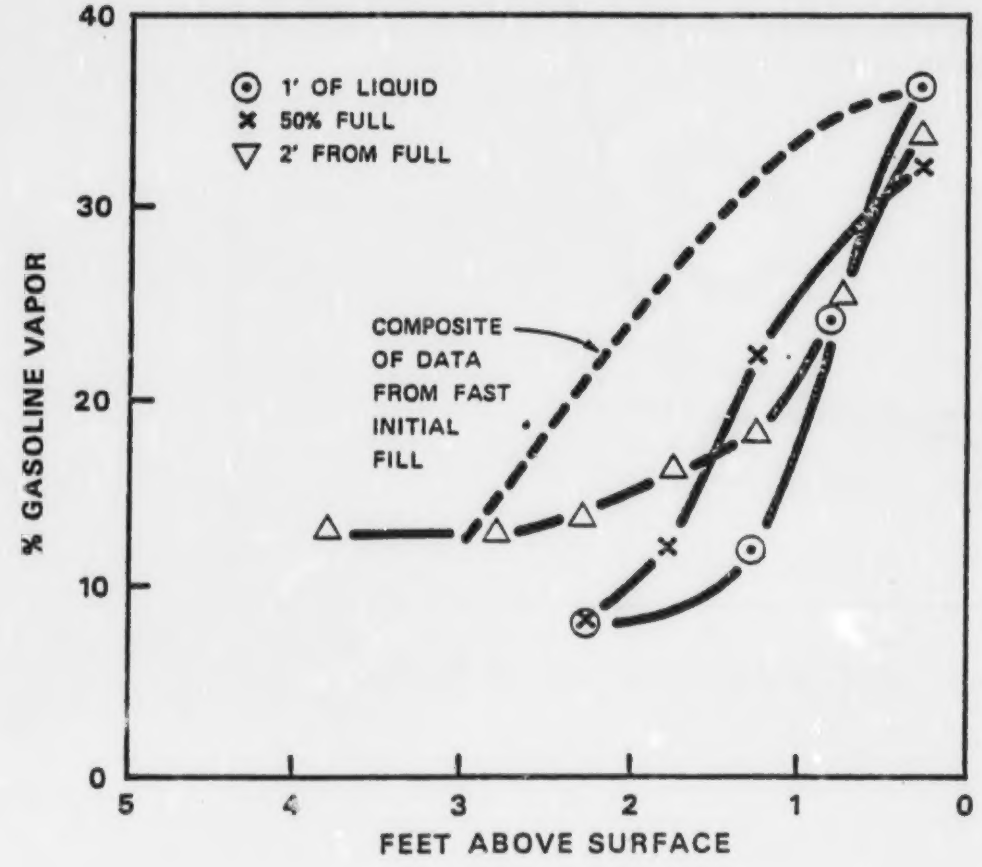


FIGURE 2

GASOLINE VAPOR EMITTED DURING FILLING
AMOCO ILLINOIS NOV.6, 1974

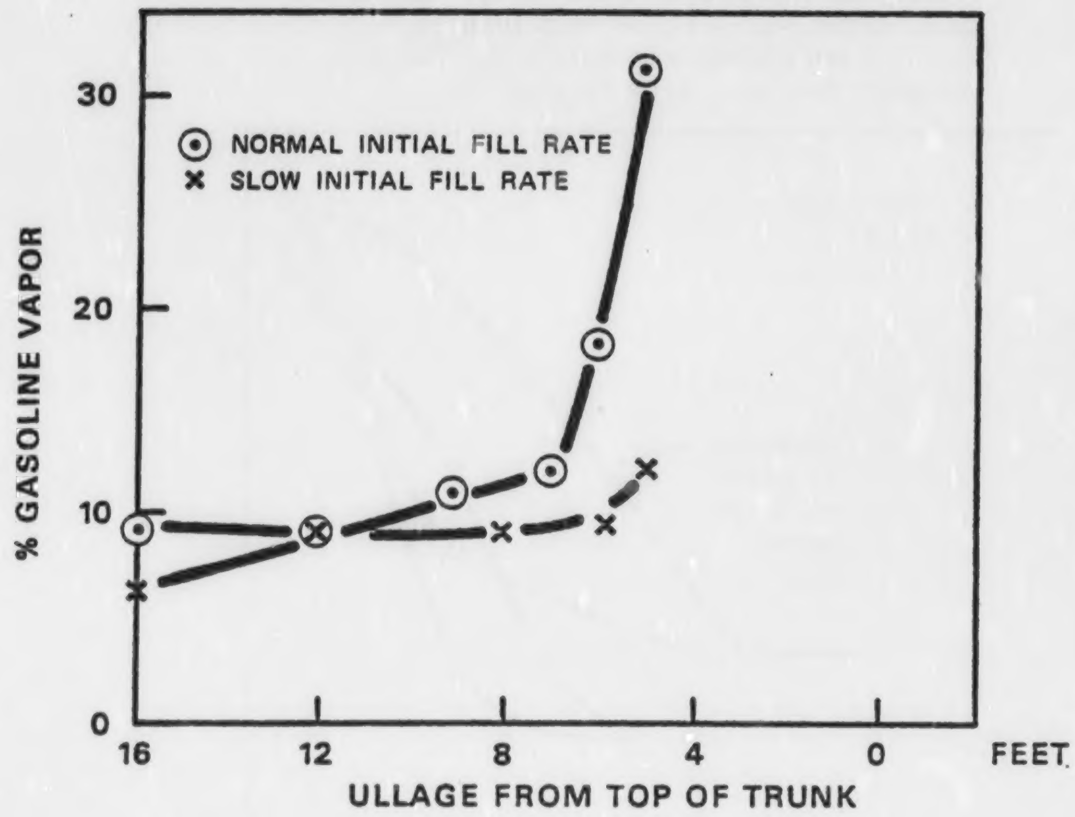


FIGURE 3

GASOLINE VAPOR EMITTED DURING LOADING

AMOCO CONNECTICUT
TEXAS CITY – NOV.21,1974

AMOCO REGULAR

⊙ NORMAL FILL RATE – 2 HOURS 20 MIN. TO FILL
× SLOW INITIAL FILL RATE – 6 INCHES IN 6 MINUTES THEN NORMAL FILL – 2 HOURS 20 MIN. TO FILL

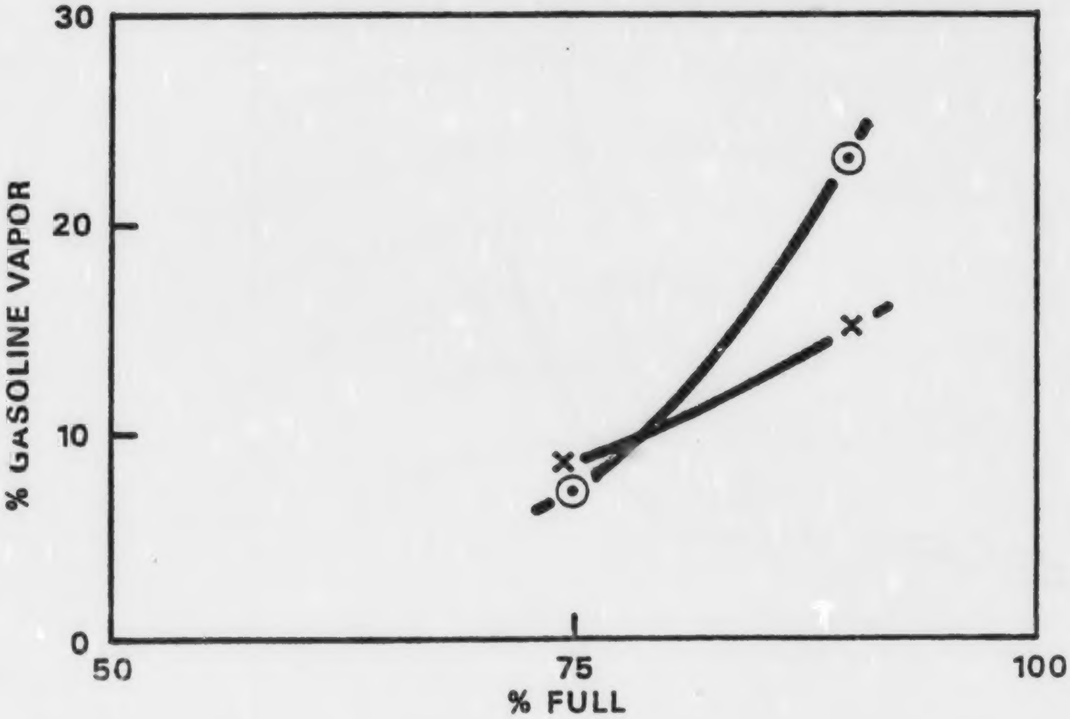


FIGURE 4

GASOLINE VAPOR EMITTED DURING LOADING

AMOCO WISCONSIN – WHITING, INDIANA
NOV.22,1974
FILLING RATE 4300 BPH
AMBIENT TEMP. 41° – FUEL TEMP. 42°

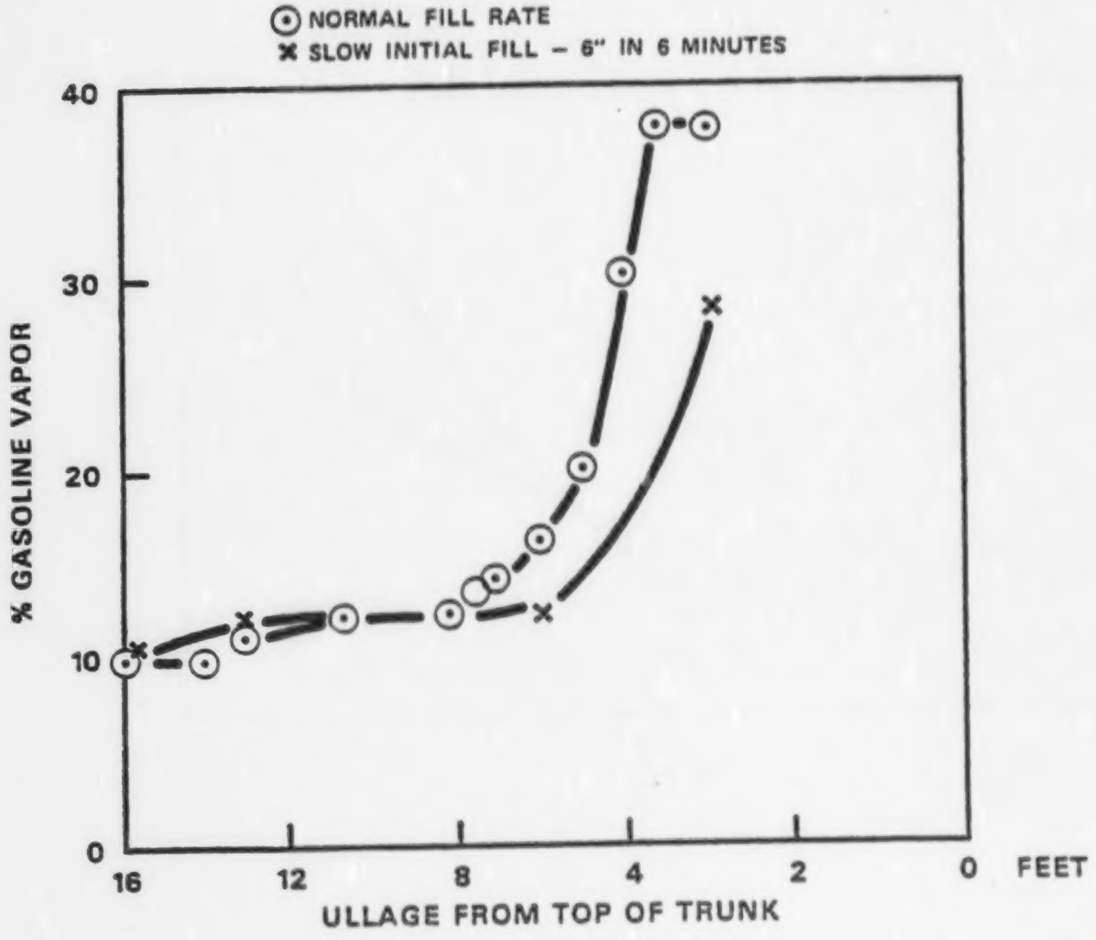


FIGURE 5

EFFECT OF SLOW FINAL LOADING

GASOLINE VAPOR EMITTED DURING LOADING

AMOCO WISCONSIN - WHITING, INDIANA
DEC.5,1974 – NORMAL LODING RATE 4200 BPH
AMBIENT TEMP. 37° FULL TEMP. 42°
RVP 11.8 PSIA

⊙ FILL FIRST FOOT IN 15 MINUTES – THEN NORMAL FILL
× FILL FIRST FOOT IN 14 MINUTES – THEN NORMAL— FILL LAST 2 FEET IN 16 MINUTES

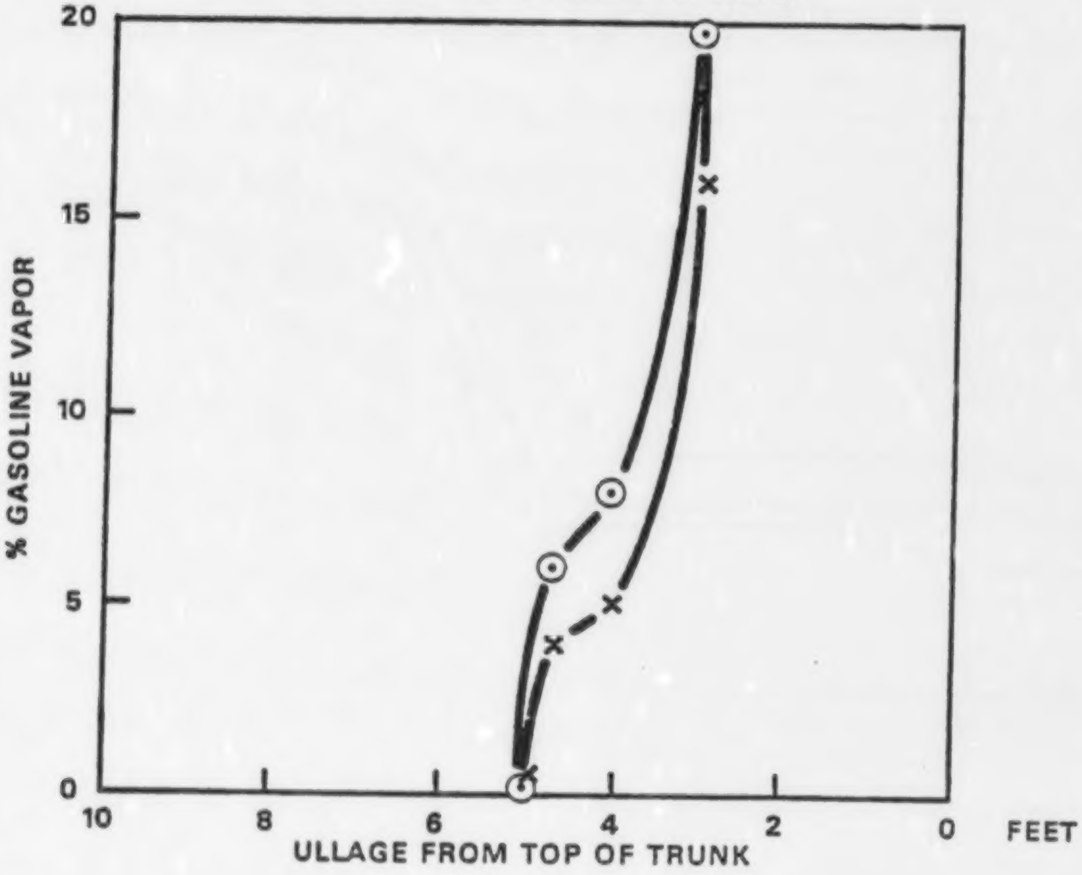


FIGURE 6

GASOLINE VAPOR EMITTED DURING LOADING

AMOCO INDIANA – DEC.27,1974
WHITING, INDIANA
AMBIENT TEMP. 36° – FUEL TEMP. 36°
FILL RATE 4400 BPH RVP 12.8 PSIA

○ NORMAL FILL
✕ FILL FIRST FOOT IN 8 MINUTES – THEN NORMAL – LAST 2 FEET SLOWLY
▽ FILL FIRST 2 FEET IN 20 MINUTES – THEN NORMAL – LAST 2 FEET SLOWLY

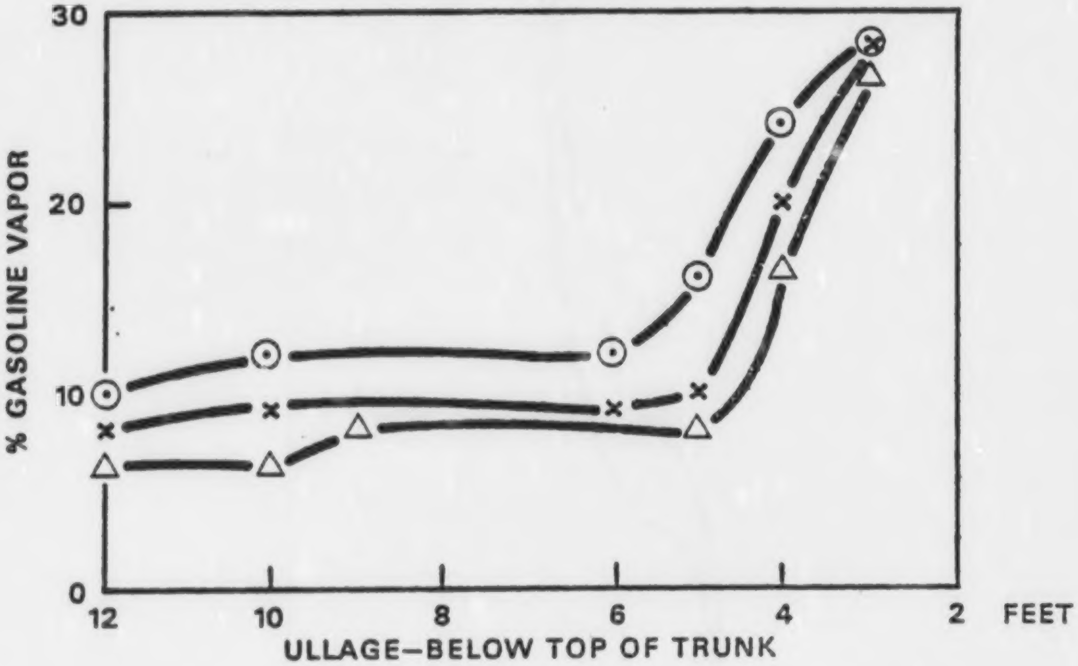
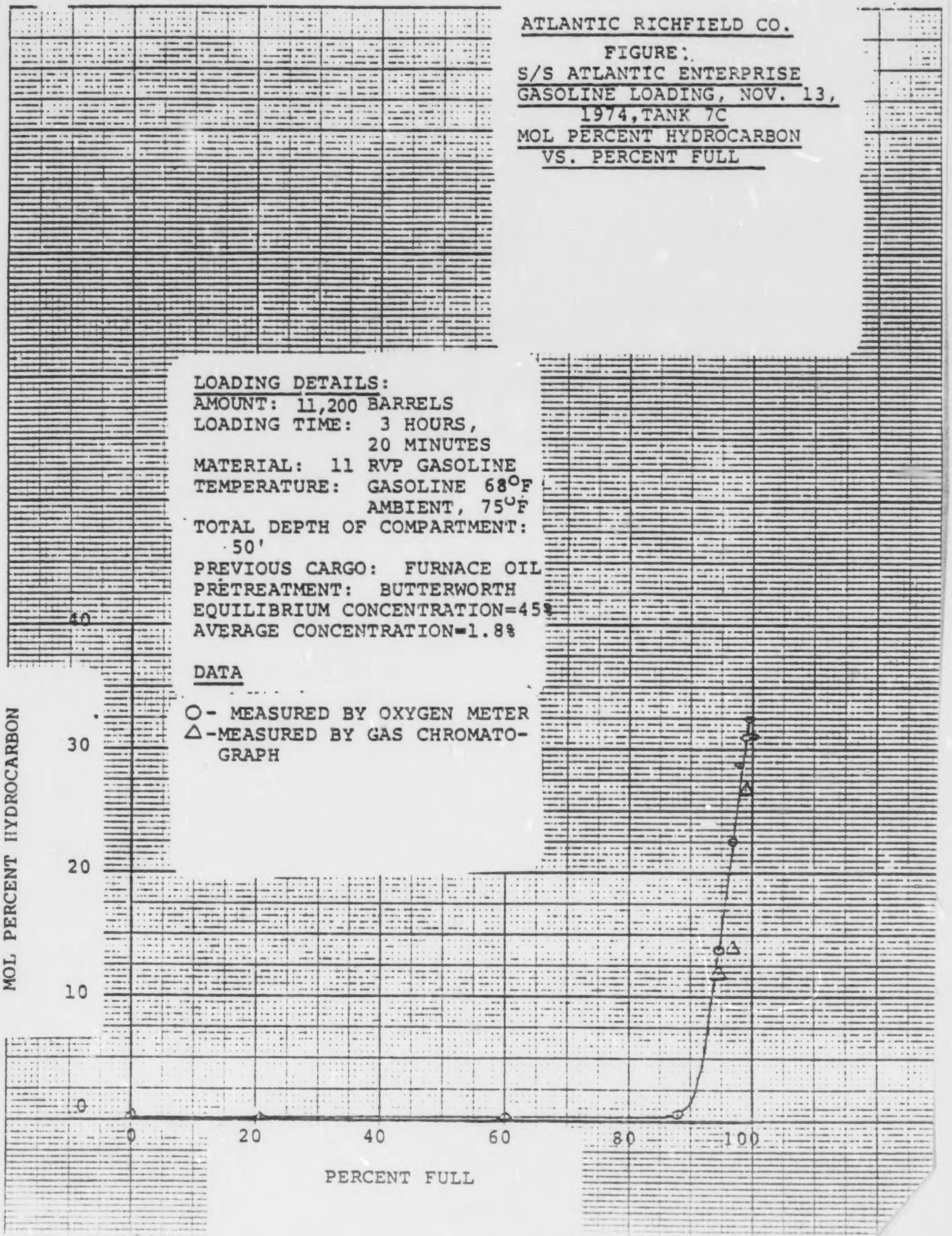


FIGURE 7

ARCO TEST RESULTS

(Reference 6)



ATLANTIC RICHFIELD CO.

FIGURE:

S/S ATLANTIC ENTERPRISE
GASOLINE LOADING, NOV. 13, 1974, TANK 7C
MOL PERCENT HYDROCARBON VS. PERCENT FULL

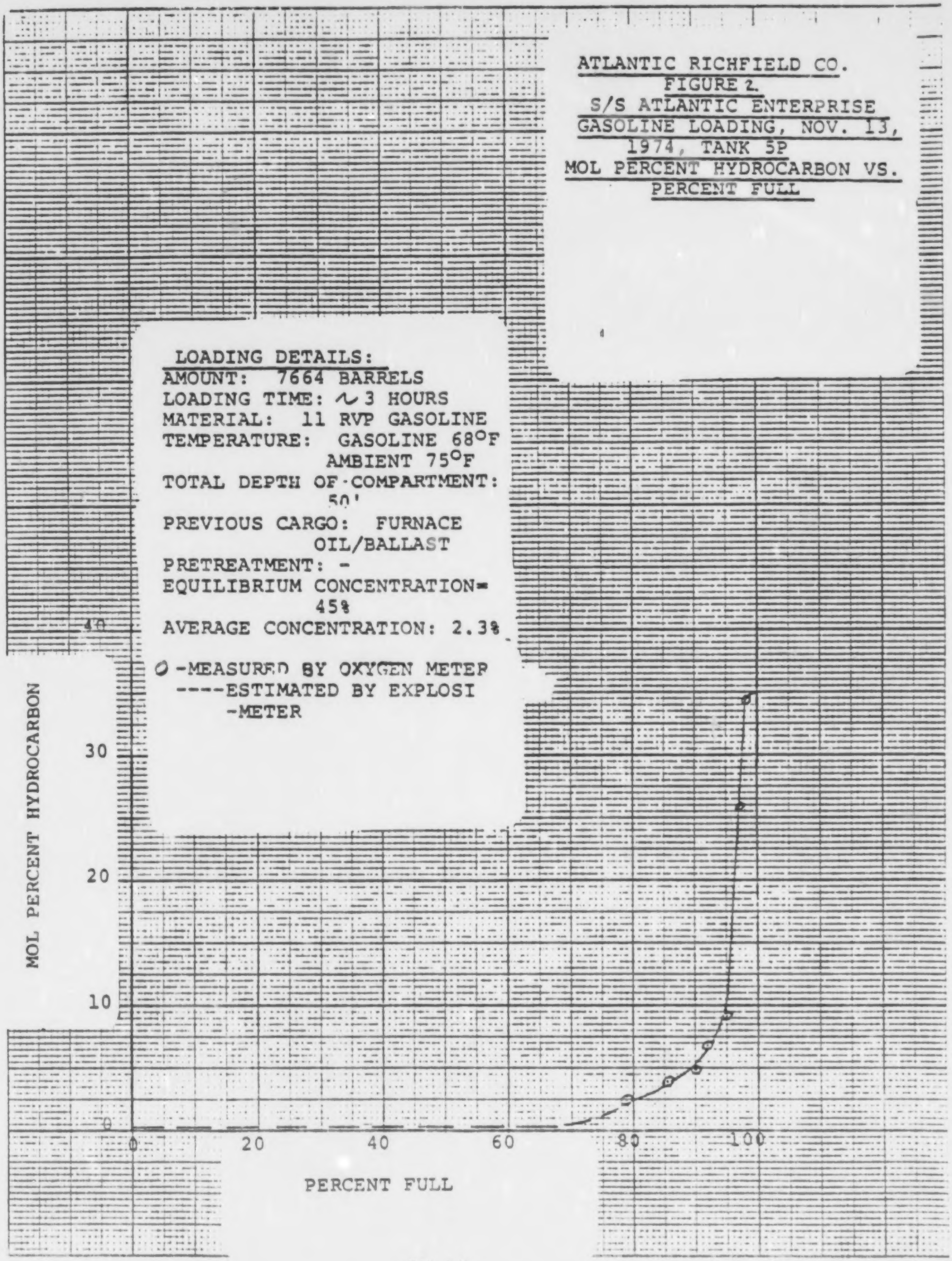
LOADING DETAILS:
AMOUNT: 11,200 BARRELS
LOADING TIME: 3 HOURS, 20 MINUTES
MATERIAL: 11 RVP GASOLINE
TEMPERATURE: GASOLINE 68°F
AMBIENT, 75°F
TOTAL DEPTH OF COMPARTMENT: 50'
PREVIOUS CARGO: FURNACE OIL
PRETREATMENT: BUTTERWORTH
EQUILIBRIUM CONCENTRATION=45%
AVERAGE CONCENTRATION=1.8%

DATA

○ - MEASURED BY OXYGEN METER
△ - MEASURED BY GAS CHROMATOGRAPH

MOL PERCENT HYDROCARBON
40
30
20
10
0
0
20
40
60
80
100
PERCENT FULL

ATLANTIC RICHFIELD CO.
FIGURE 2.
S/S ATLANTIC ENTERPRISE GASOLINE LOADING, NOV. 13, 1974, TANK 5P MOL PERCENT HYDROCARBON VS. PERCENT FULL



LOADING DETAILS:

AMOUNT: 7664 BARRELS
LOADING TIME: ~3 HOURS
MATERIAL: 11 RVP GASOLINE
TEMPERATURE: GASOLINE 68°F
AMBIENT 75°F
TOTAL DEPTH OF COMPARTMENT: 50'
PREVIOUS CARGO: FURNACE OIL/BALLAST
PRETREATMENT: -
EQUILIBRIUM CONCENTRATION= 45%
AVERAGE CONCENTRATION: 2.3%

ATLANTIC RICHFIELD COMPANY

TABLE I

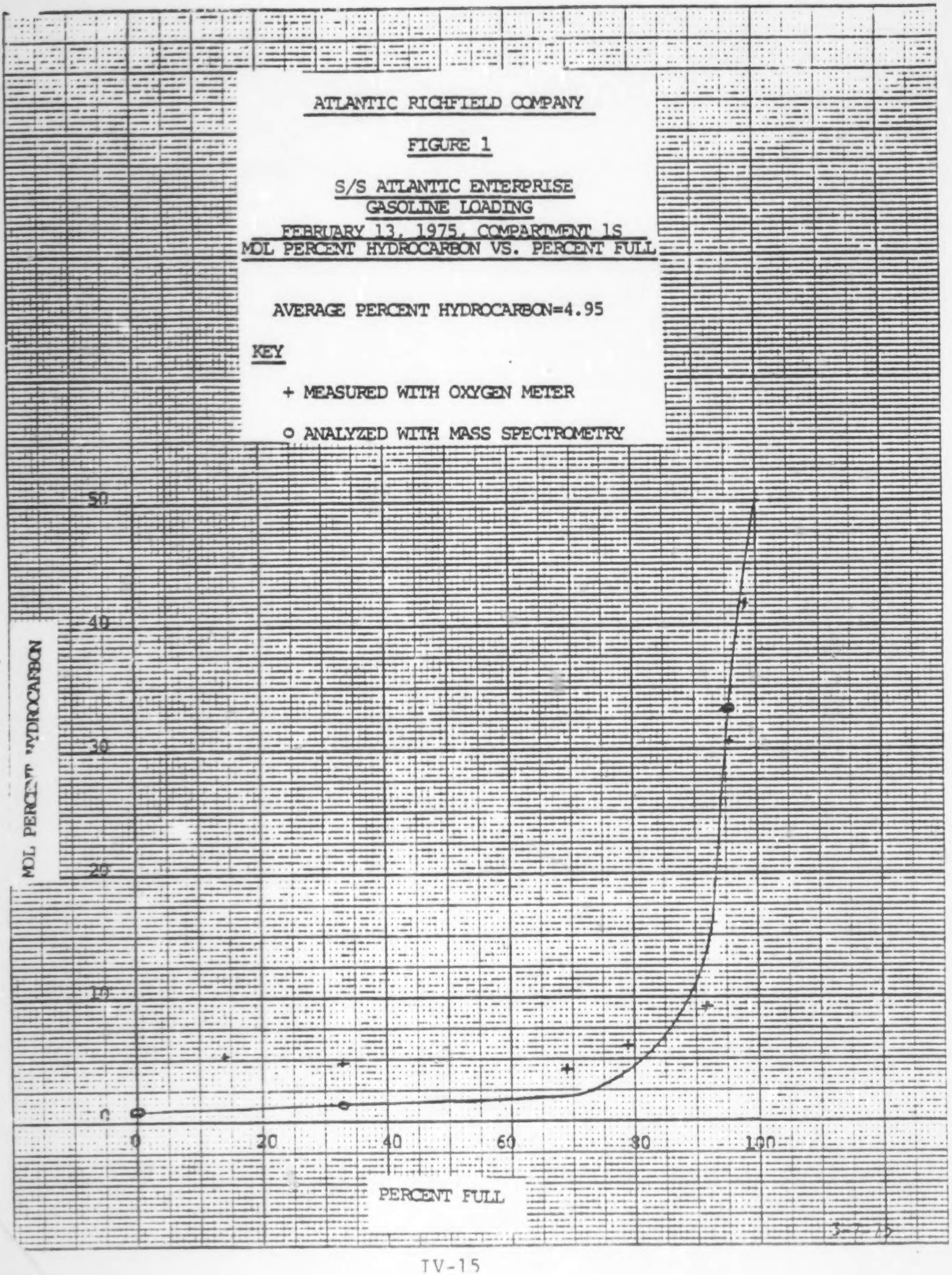
S/S ATLANTIC ENTERPRISE, FEBRUARY 13, 1975
VOLATILE PRODUCT LOADING AND EMISSION DATA

	COMPARTMENT				
LOADING INFORMATION	1s	5 s	7s	8s	9s
AMOUNT, BARRELS	4,401	7,590	7,573	7,493	7,272
TIME, HOURS	17.2	16.0	15.7	17.6	17.9
CARGO	Clear Gasoline	Clear Gasoline	Clear Gasoline	Clear Gasoline	Clear Gasoline
PREVIOUS CARGO	Furnace Oil	Regular Gasoline	Clear Gasoline	Premium Gasoline	Furnace Oil
PRETREATMENT	Flood Bottom Strip Dry	Butterworth Strip Dry	Strip Dry	Butterworth Strip Dry	Flood Bottom Strip Dry
TEMPERATURE, CARGO, °F	70	70	70	70	70
AMBIENT, °F	45-70	45-70	45-70	45-70	45-70
FINAL HEIGHT OF LIQUID, FT.	44	46	46	46	46
RVP, PSIA	13.5	13.5	13.5	13.5	13.5
HYDROCARBON CONCENTRATIONS					
EQUILIBRIUM VAPOR, MOL PERCENT	58.5	58.5	58.5	58.5	58.5
AVERAGE EMISSION*:					
MOL PERCENT	4.95	5.5	7.0	8.2	3.4
PARTIAL PRESSURE, PSIA	0.73	0.81	1.0	1.2	0.50

*FROM FIGURES 1-5 INCLUSIVE

PWW:lk

3/7/75



ATLANTIC RICHFIELD COMPANY

FIGURE 1

S/S ATLANTIC ENTERPRISE
GASOLINE LOADING
FEBRUARY 13, 1975, COMPARTMENT 1S
MOL PERCENT HYDROCARBON VS. PERCENT FULL

AVERAGE PERCENT HYDROCARBON=4.95

KEY

+ MEASURED WITH OXYGEN METER

o ANALYZED WITH MASS SPECTROMETRY

3-7-75

ATLANTIC RICHFIELD COMPANY

FIGURE 2

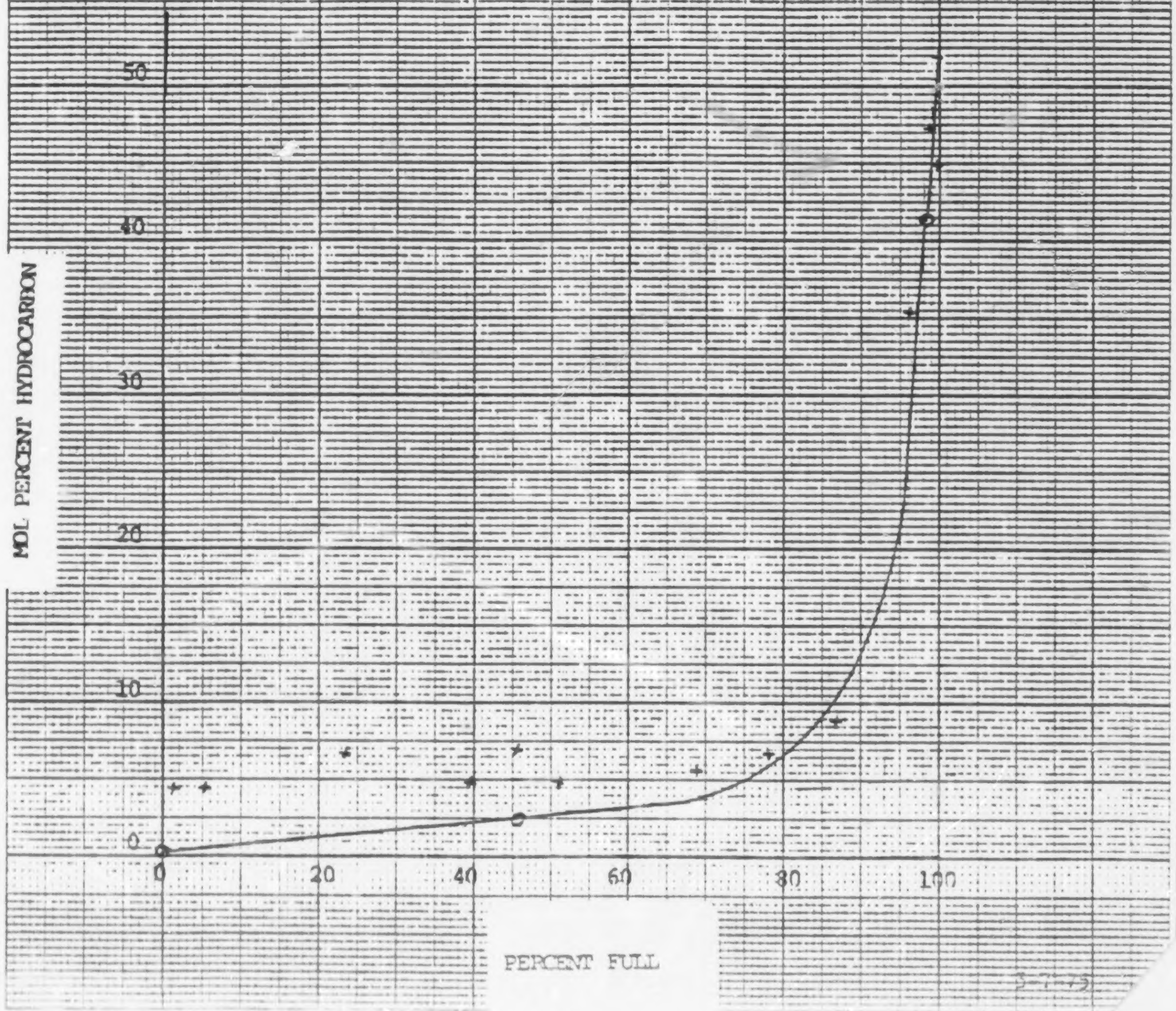
S/S ATLANTIC ENTERPRISE
GASOLINE LOADING
FEBRUARY 13, 1975
COMPARTMENT 5S
MOL PERCENT HYDROCARBON IN EMISSIONS VS. PERCENT FULL

AVERAGE HYDROCARBON PERCENT= 5.5

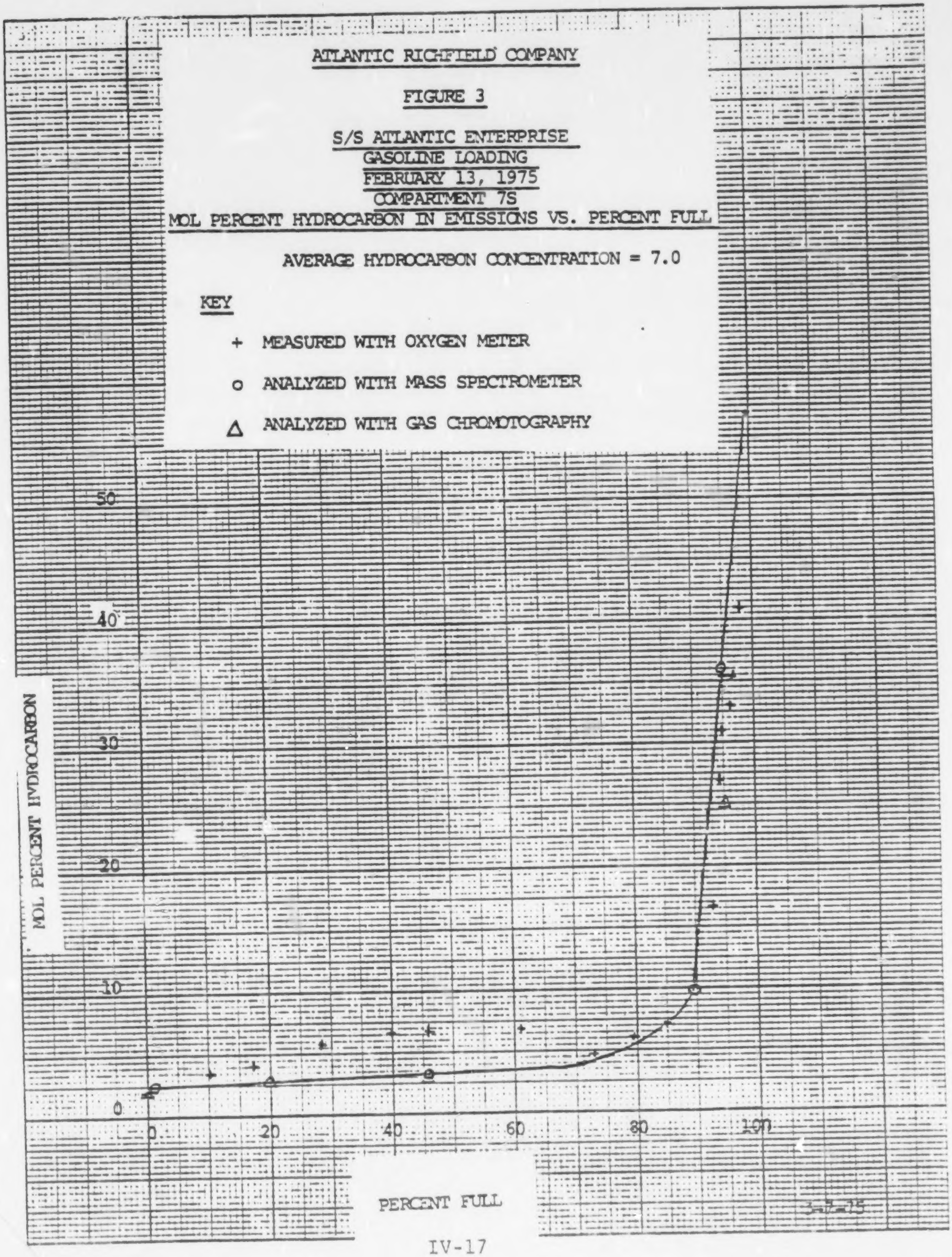
KEY

+ MEASURED WITH OXYGEN METER

o ANALYZES BY MASS SPECTROMETRY



3-7-75



ATLANTIC RICHFIELD COMPANY

FIGURE 3

S/S ATLANTIC ENTERPRISE
GASOLINE LOADING
FEBRUARY 13, 1975
COMPARTMENT 7S
MOL PERCENT HYDROCARBON IN EMISSIONS VS. PERCENT FULL

AVERAGE HYDROCARBON CONCENTRATION = 7.0

KEY

+ MEASURED WITH OXYGEN METER

○ ANALYZED WITH MASS SPECTROMETER

△ ANALYZED WITH GAS CHROMOTOGRAPHY

ATLANTIC RICHFIELD COMPANY

FIGURE 4

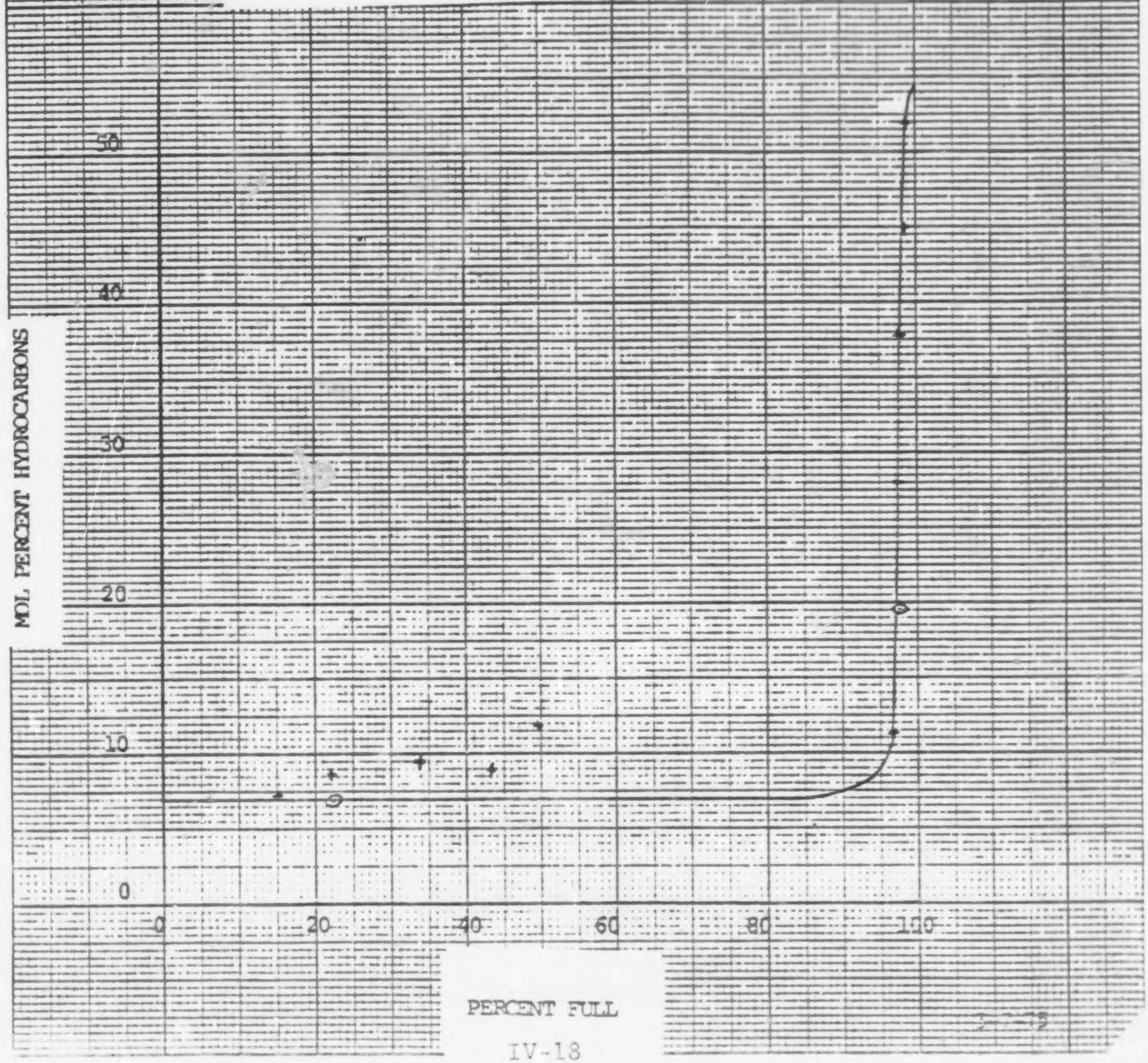
S/S ATLANTIC ENTERPRISE
GASOLINE LOADING
FEBRUARY 13, 1975
COMPARTMENT 8S
MOL PERCENT HYDROCARBON IN EMISSIONS VS. PERCENT FULL

AVERAGE HYDROCARBON CONCENTRATION=8.2

KEY

+ MEASURED WITH OXYGEN METER

o ANALYZED WITH MASS SPECTROMETER



ATLANTIC RICHFIELD COMPANY

FIGURE 5

S/S ATLANTIC ENTERPRISE
GASOLINE LOADING
FEBRUARY 13, 1975
COMPARTMENT 9S
MOL PERCENT HYDROCARBON IN EMISSIONS VS. PERCENT FULL

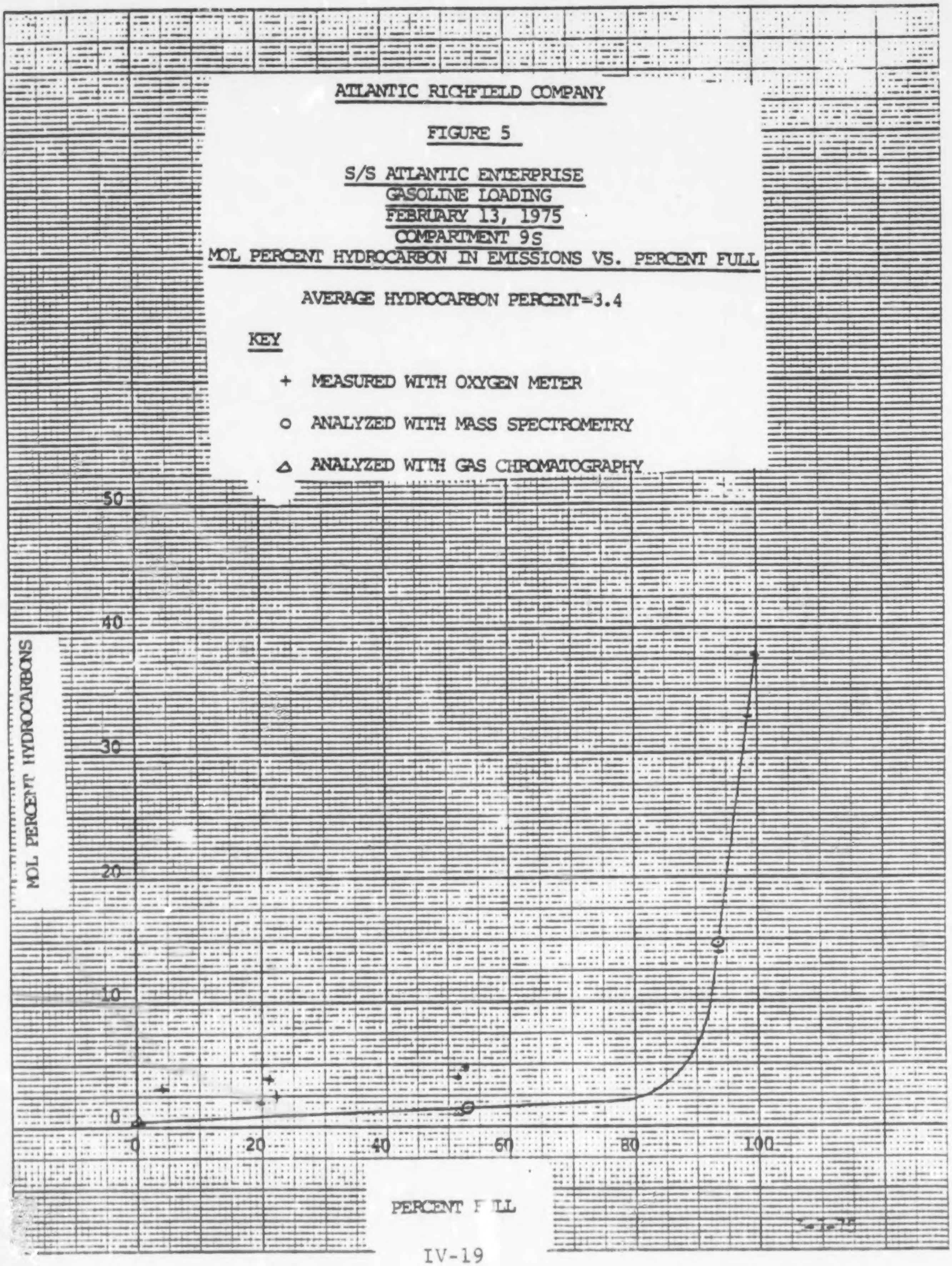
AVERAGE HYDROCARBON PERCENT=3.4

KEY

+ MEASURED WITH OXYGEN METER

○ ANALYZED WITH MASS SPECTROMETRY

△ ANALYZED WITH GAS CHROMATOGRAPHY



ATLANTIC RICHFIELD COMPANY

TABLE I

VOLATILE PRODUCT LOADING AND EMISSION DATA
S/S ARCO PRESTIGE, APRIL 28, 1975

LOADING INFORMATION	COMPARTMENT			
	1C	4C	7C	11C
Amount, Barrels	10011	12974	12974	8912
Time, Hours	1.7	3.8	3.5	2.0
Average Fill Rate				
BPH	5889	3414	3707	4456
GPM	4122	2390	2595	3119
Cargo	Clear Gasoline	Clear Gasoline	Clear Gasoline	Clear Gasolin
Previous Cargo	Furnace Oil	Leaded Gasoline	Leaded Gasoline	Furnace Oil
Pretreatment	Flood Bottom Strip Dry	Butterworth Hot Wash Strip Dry Ballasted	Butterworth Hot Wash Strip Dry Ballasted	Flood Bottom Strip Dry
Temperature, Cargo °F	87	87	87	87
, Ambient °F	80-84	80-84	80-84	80-84
Final Height of Liquid, Feet	45.7	45.7	45.7	45.7
RVP, PSIA	9.7	9.7	9.7	9.7
TVP, PSIA	8.0	8.0	8.0	8.0
HYDROCARBON CONCENTRATIONS				
Equilibrium Vapor Mol Percent	54.4	54.4	54.4	54.4
Average Emission*				
Mol Percent	2.8	3.0	1.8	2.6
Partial Pressure PSIA	0.41	0.44	0.43	0.38

*Based on "mol percent hydrocarbon versus percent full" curves.

GJZ:lk

4.

ATLANTIC RICHFIELD COMPANY

TABLE II

SUMMARY OF SAMPLE DATA FROM UNLEADED GASOLINE LOADING TEST-S/S ARCO PRESTIGE

APRIL 28, 1975

			PERCENT HYDROCARBON		
COMPART-MENT	TIME P.M.	PERCENT FULL	MASS SPEC.	GAS CHROM.	MOL. WEIGHT MASS SPEC.
7C	2:45	2	0.03	0.03	58.13
7C	3:20	28	0.04	0.06	56.66
7C	4:52	71	0.13	0.16	57.01
7C	5:22	88	0.22	0.63	55.03
7C	5:55	96	17.44	24.0	57.86
7C	6:05	98	39.07	33.0	56.67
4C	2:48	3	0.02	-	58.11
4C	3:30	22	0.03	-	58.11
4C	5:00	65	0.24	-	51.38
4C	6:15	92	8.78	-	55.26
4C	6:26	97	34.20	-	56.78
4C	6:32	99	38.73	-	56.95
1C	6:35	4	0.98	-	65.99
1C	8:00	96	25.76	-	55.03
1C	8:05	98	23.69	-	55.16
11C	6:10	5	0.13	-	65.95
11C	7:50	96	24.84	-	59.90
11C	7:54	99	24.68	-	56.01

GJZ:lk
8/22/75

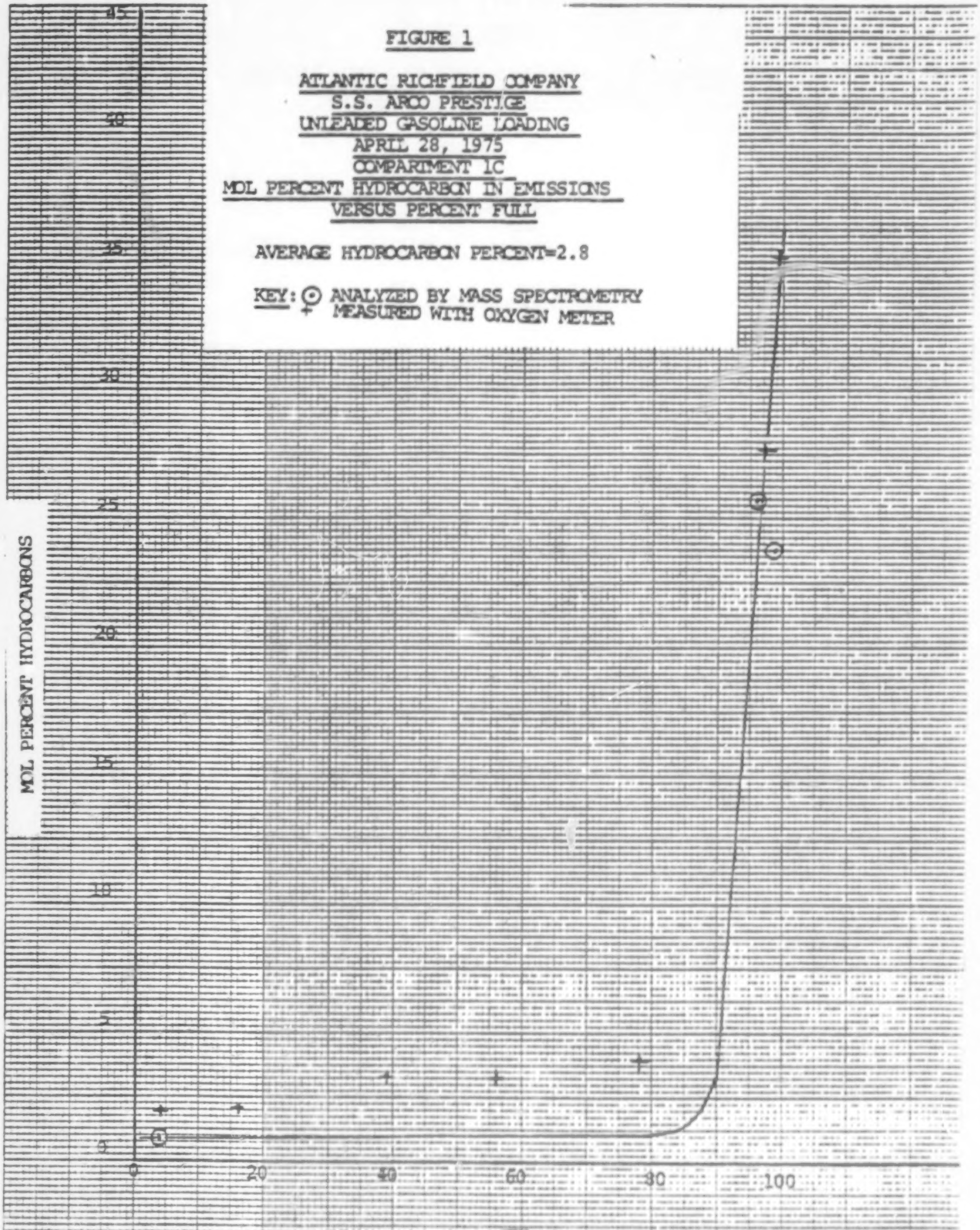


FIGURE 1

ATLANTIC RICHFIELD COMPANY
S.S. ARCO PRESTIGE
UNLEADED GASOLINE LOADING
APRIL 28, 1975
COMPARTMENT 1C
MOL PERCENT HYDROCARBON IN EMISSIONS
VERSUS PERCENT FULL

AVERAGE HYDROCARBON PERCENT=2.8

KEY: ⊙ ANALYZED BY MASS SPECTROMETRY
+ MEASURED WITH OXYGEN METER

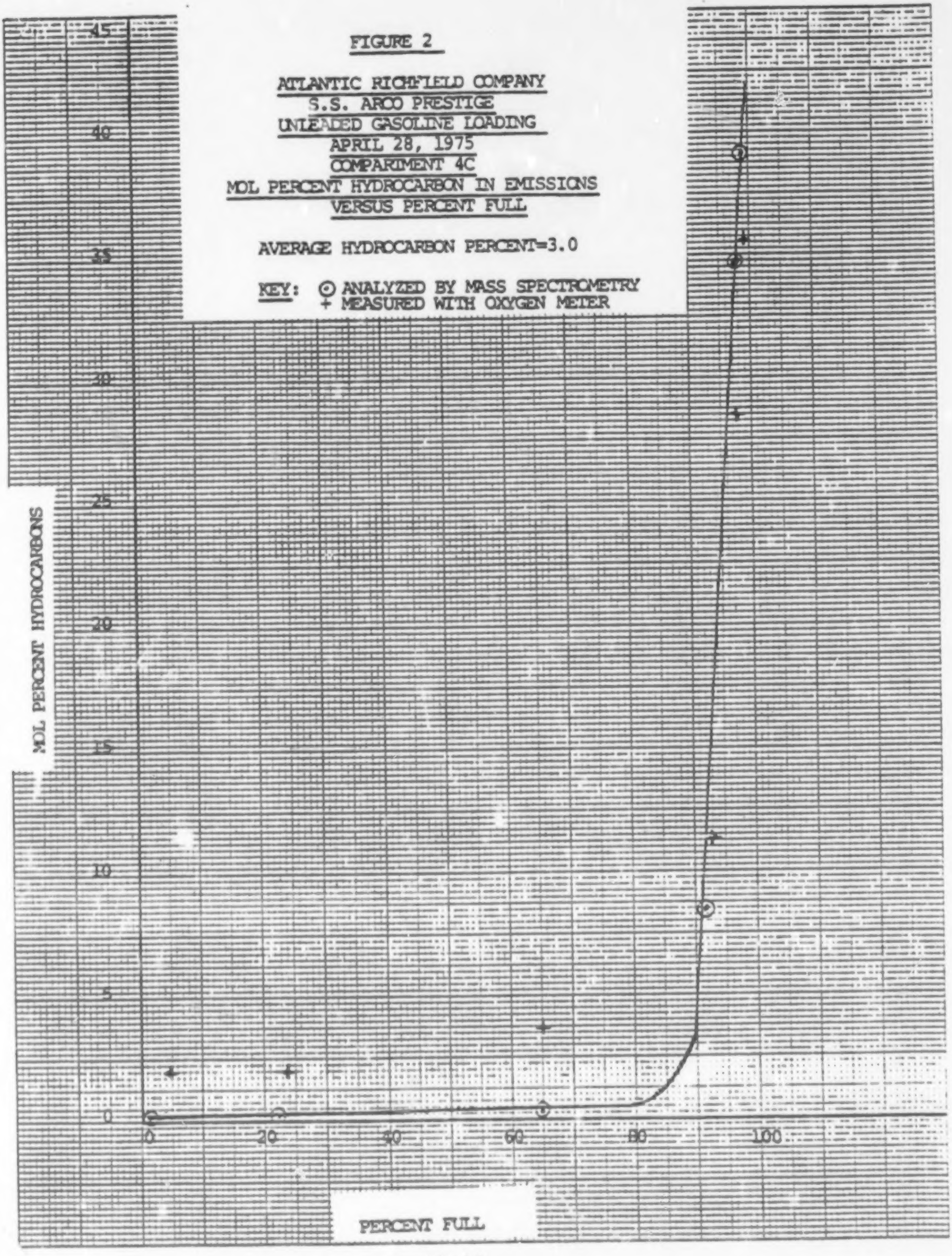


FIGURE 2

ATLANTIC RICHFIELD COMPANY
S.S. ARCO PRESTIGE
UNLEADED GASOLINE LOADING
APRIL 28, 1975
COMPARTMENT 4C
MOL PERCENT HYDROCARBON IN EMISSIONS
VERSUS PERCENT FULL

AVERAGE HYDROCARBON PERCENT=3.0

KEY: ⊙ ANALYZED BY MASS SPECTROMETRY
+ MEASURED WITH OXYGEN METER

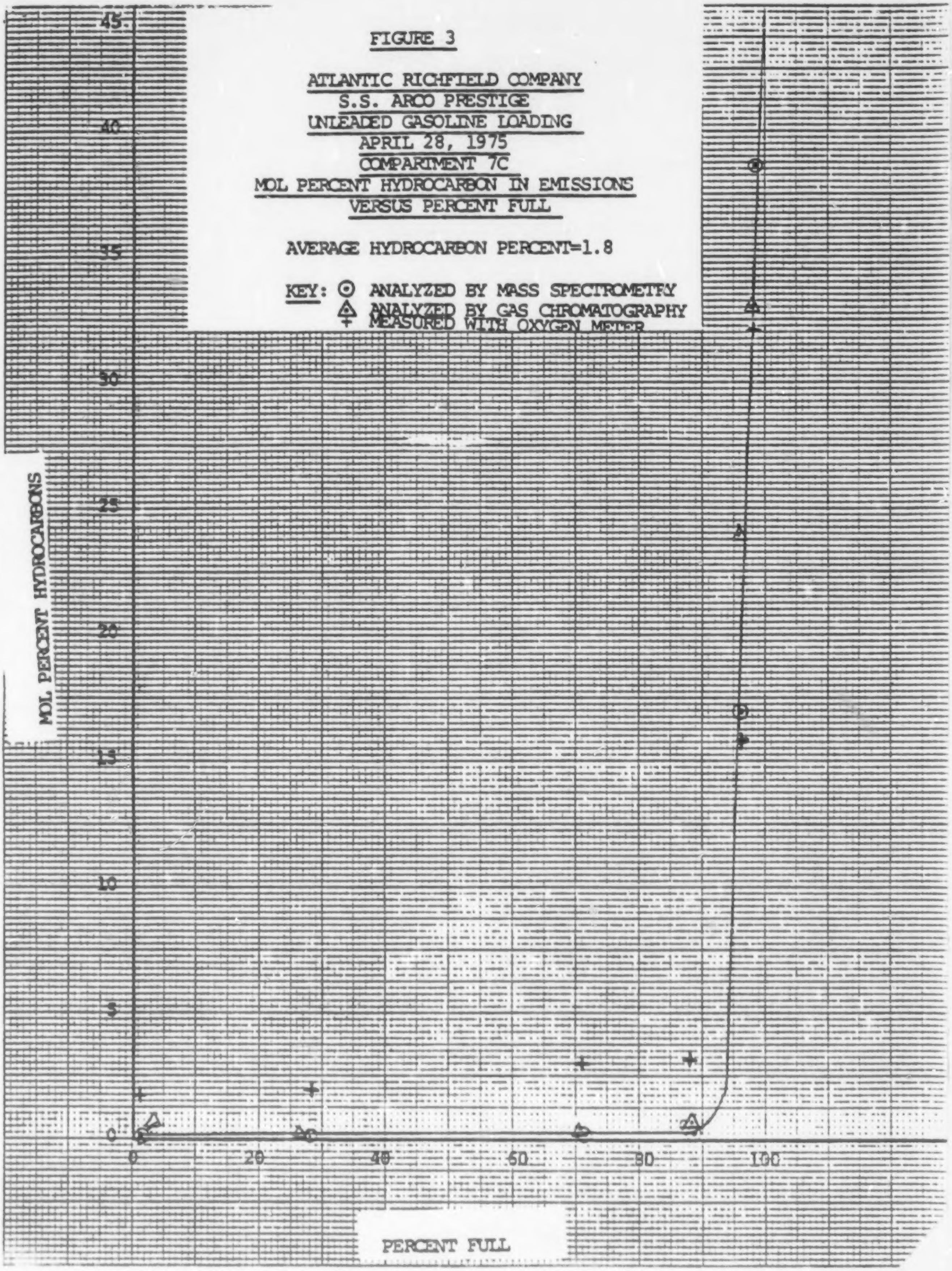


FIGURE 3

ATLANTIC RICHFIELD COMPANY
S.S. ARCO PRESTIGE
UNLEADED GASOLINE LOADING
APRIL 28, 1975
COMPARTMENT 7C
MOL PERCENT HYDROCARBON IN EMISSIONS
VERSUS PERCENT FULL

AVERAGE HYDROCARBON PERCENT=1.8

KEY: ⊙ ANALYZED BY MASS SPECTROMETRY
△ ANALYZED BY GAS CHROMATOGRAPHY
+ MEASURED WITH OXYGEN METER

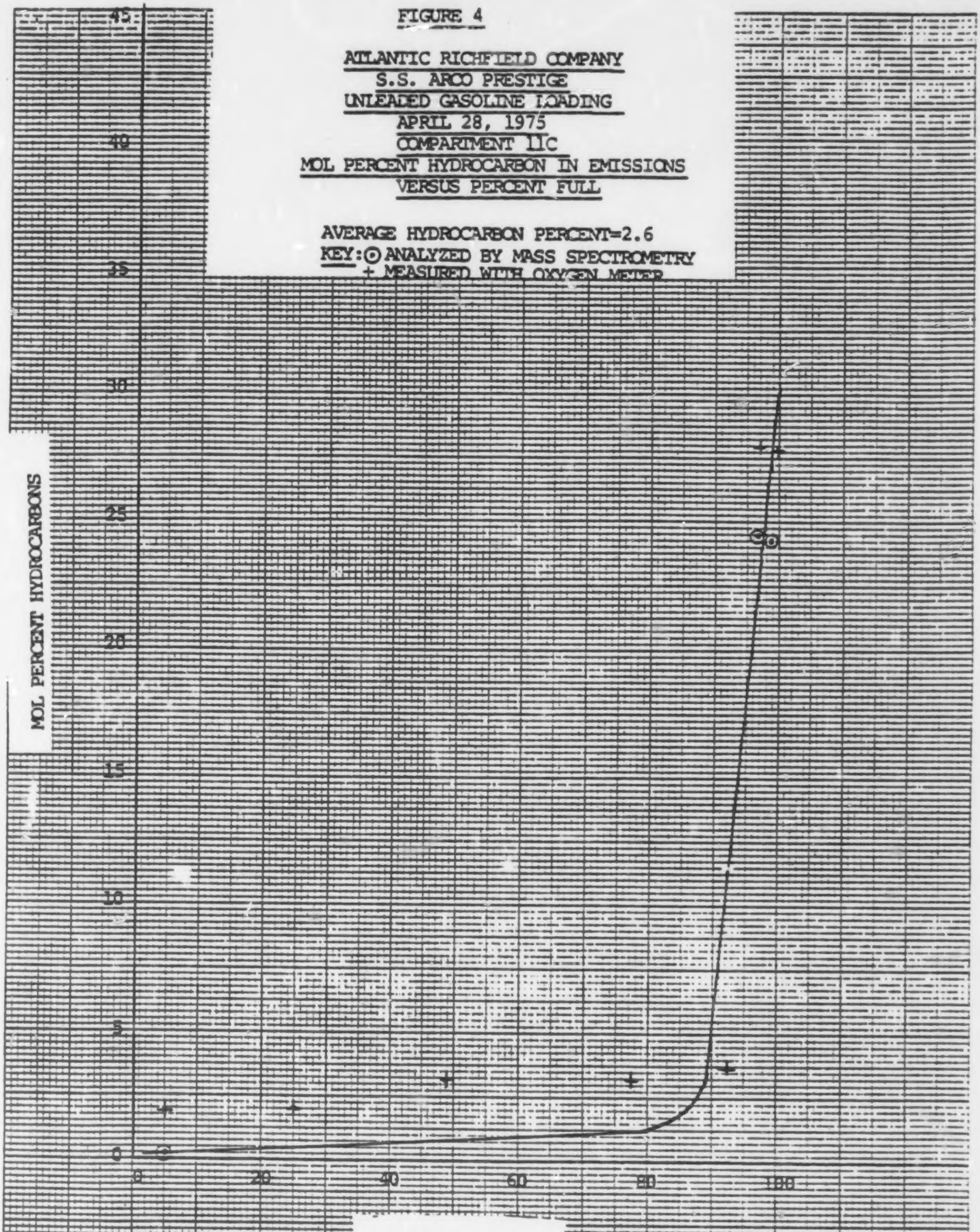


FIGURE 4

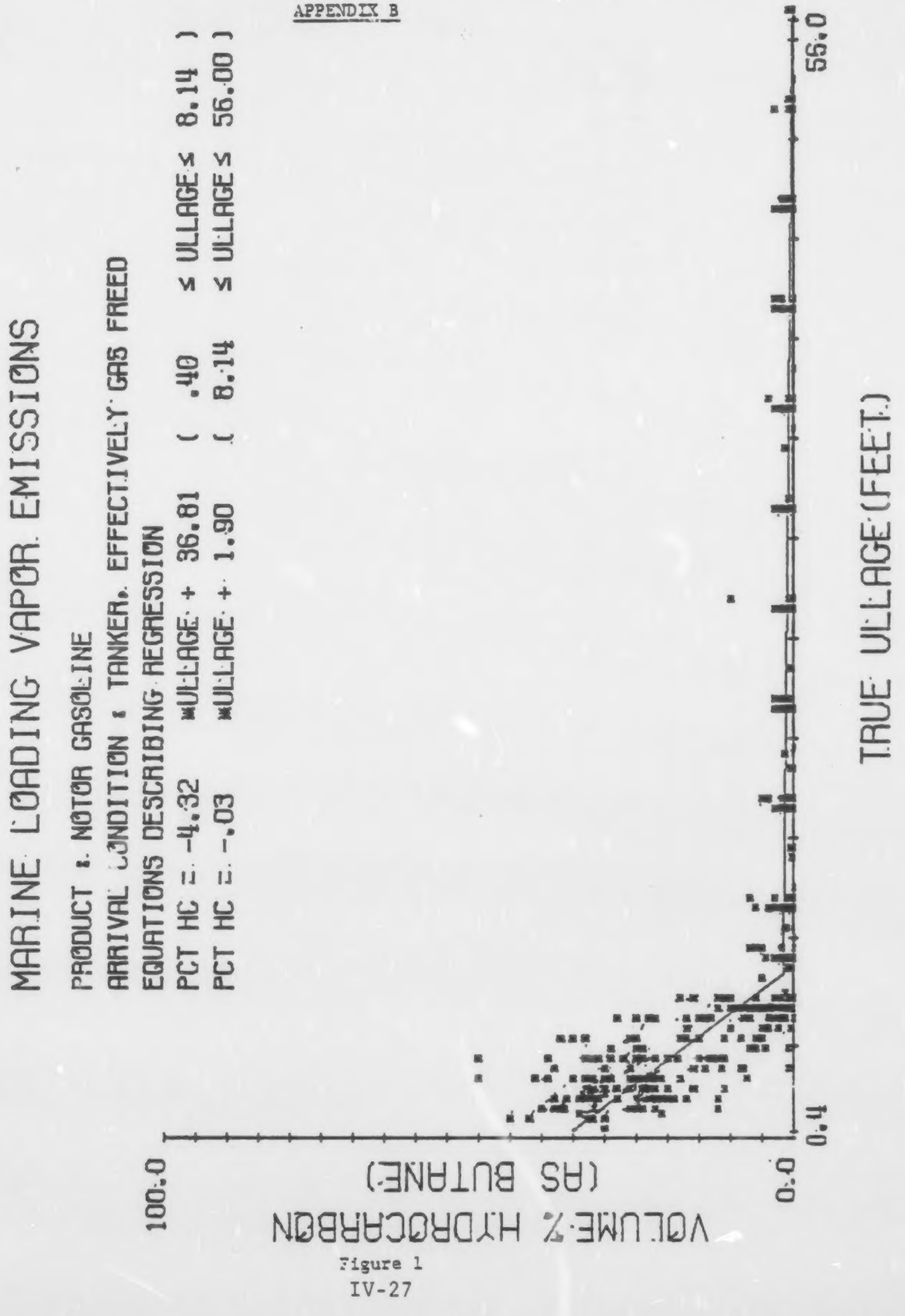
ATLANTIC RICHFIELD COMPANY
S.S. ARCO PRESTIGE
UNLEADED GASOLINE LOADING
APRIL 28, 1975
COMPARTMENT 11C
MOL PERCENT HYDROCARBON IN EMISSIONS
VERSUS PERCENT FULL

AVERAGE HYDROCARBON PERCENT=2.6
KEY: ⊙ ANALYZED BY MASS SPECTROMETRY
+ MEASURED WITH OXYGEN METER

EXXON TEST RESULTS

(Reference 13)

APPENDIX B



MARINE LOADING VAPOR EMISSIONS

PRODUCT : MOTOR GASOLINE

ARRIVAL CONDITION : TANKER. EFFECTIVELY GAS FREED

EQUATIONS DESCRIBING REGRESSION

PCT HC = -4.32 *ULLAGE + 36.81 (.40 ≤ ULLAGE ≤ 8.14)

PCT HC = -.03 *ULLAGE + 1.90 (8.14 ≤ ULLAGE ≤ 56.00)

Figure 1

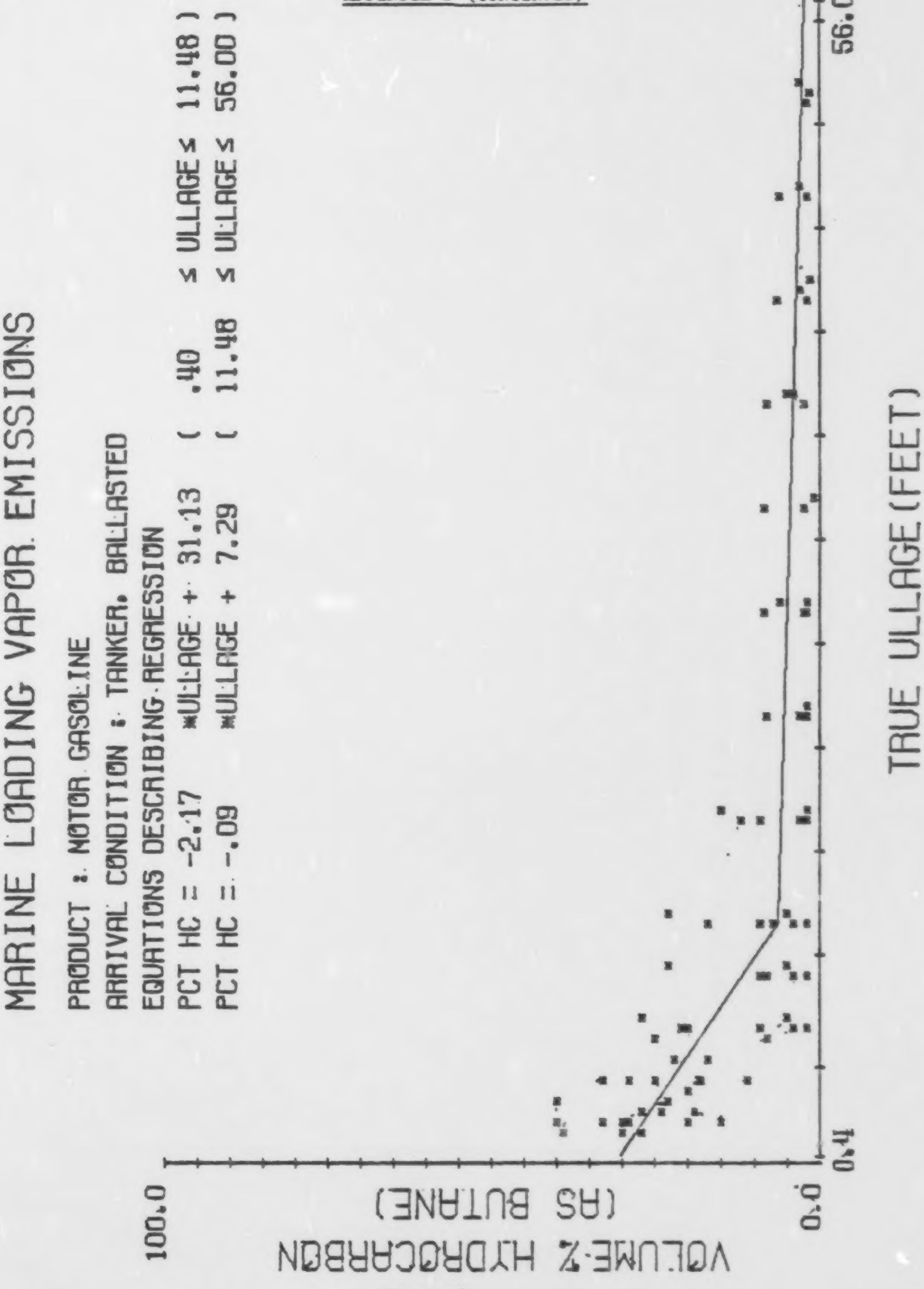

MARINE LOADING VAPOR EMISSIONS
PRODUCT : MOTOR GASOLINE
ARRIVAL CONDITION : TANKER, BALLASTED
EQUATIONS DESCRIBING REGRESSION
PCT HC = -2.17 *ULLAGE + 31.13 (.40 ≤ ULLAGE ≤ 11.48)
PCT HC = -.09 *ULLAGE + 7.29 (11.48 ≤ ULLAGE ≤ 56.00)
100.0
0.0
VOLUME-% HYDROCARBON
(AS BUTANE)
0.4
56.0
TRUE ULLAGE (FEET)

Figure 2

APPENDIX B (CONTINUED)

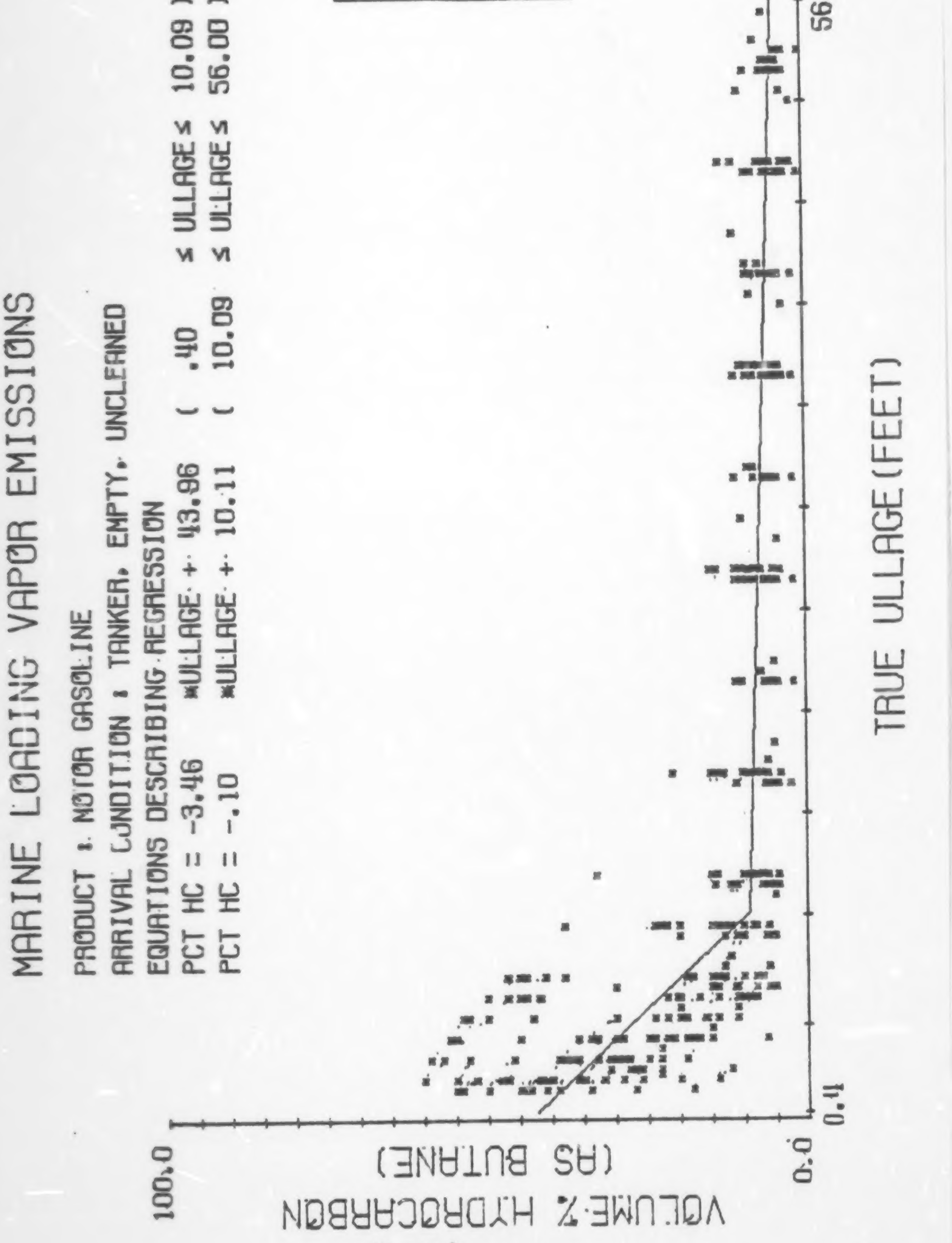


Figure 3

MARINE LOADING VAPOR EMISSIONS

PRODUCT : MOTOR GASOLINE

ARRIVAL CONDITION : OCEAN BARGE, EFFECTIVELY GAS FREED

EQUATIONS DESCRIBING REGRESSION

PCT HC = -8.51 *ULLAGE + 58.48 (2.00 ≤ ULLAGE ≤ 8.30)

PCT HC = -.17 *ULLAGE + 5.81 (8.30 ≤ ULLAGE ≤ 40.00)

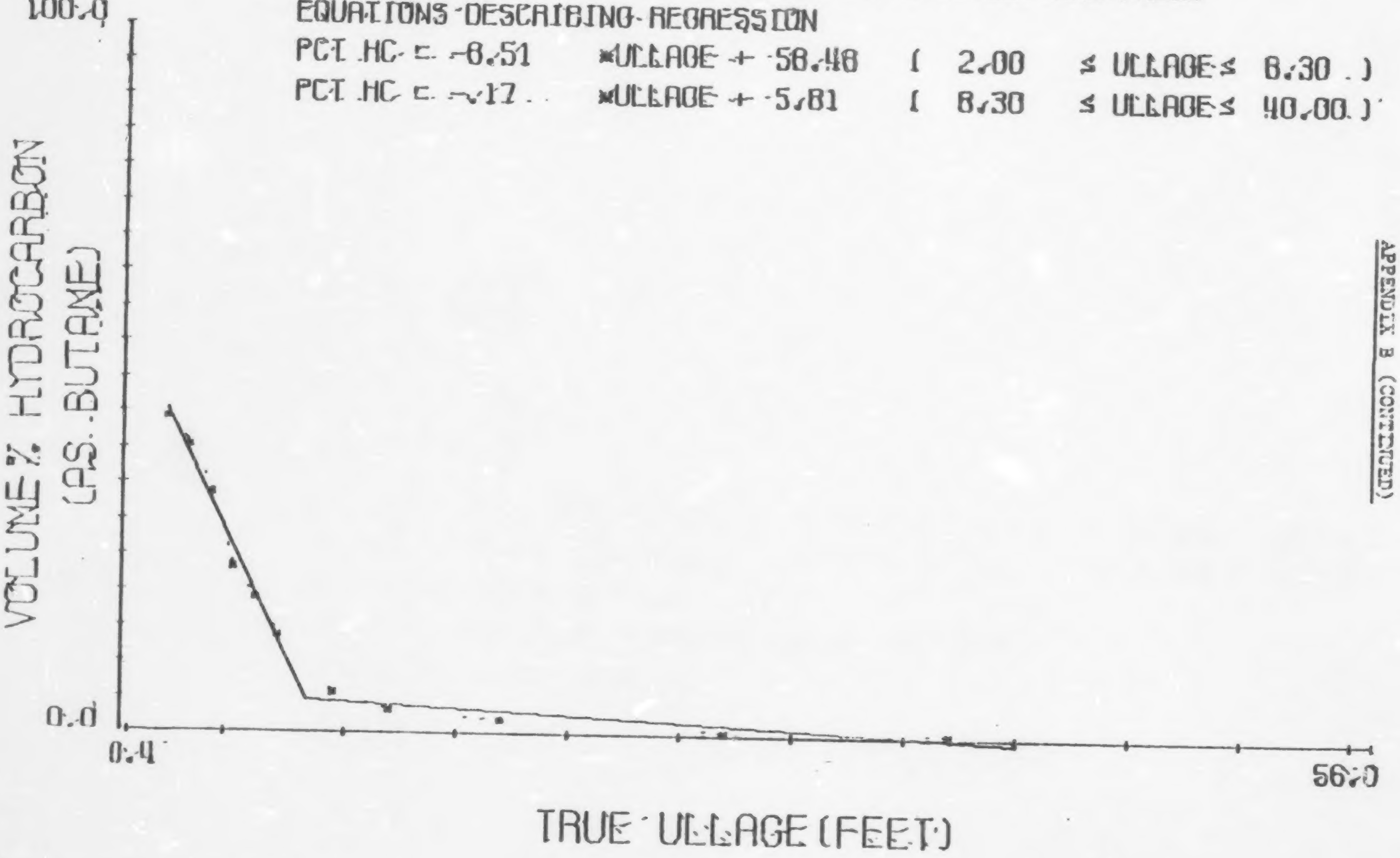


Figure 4

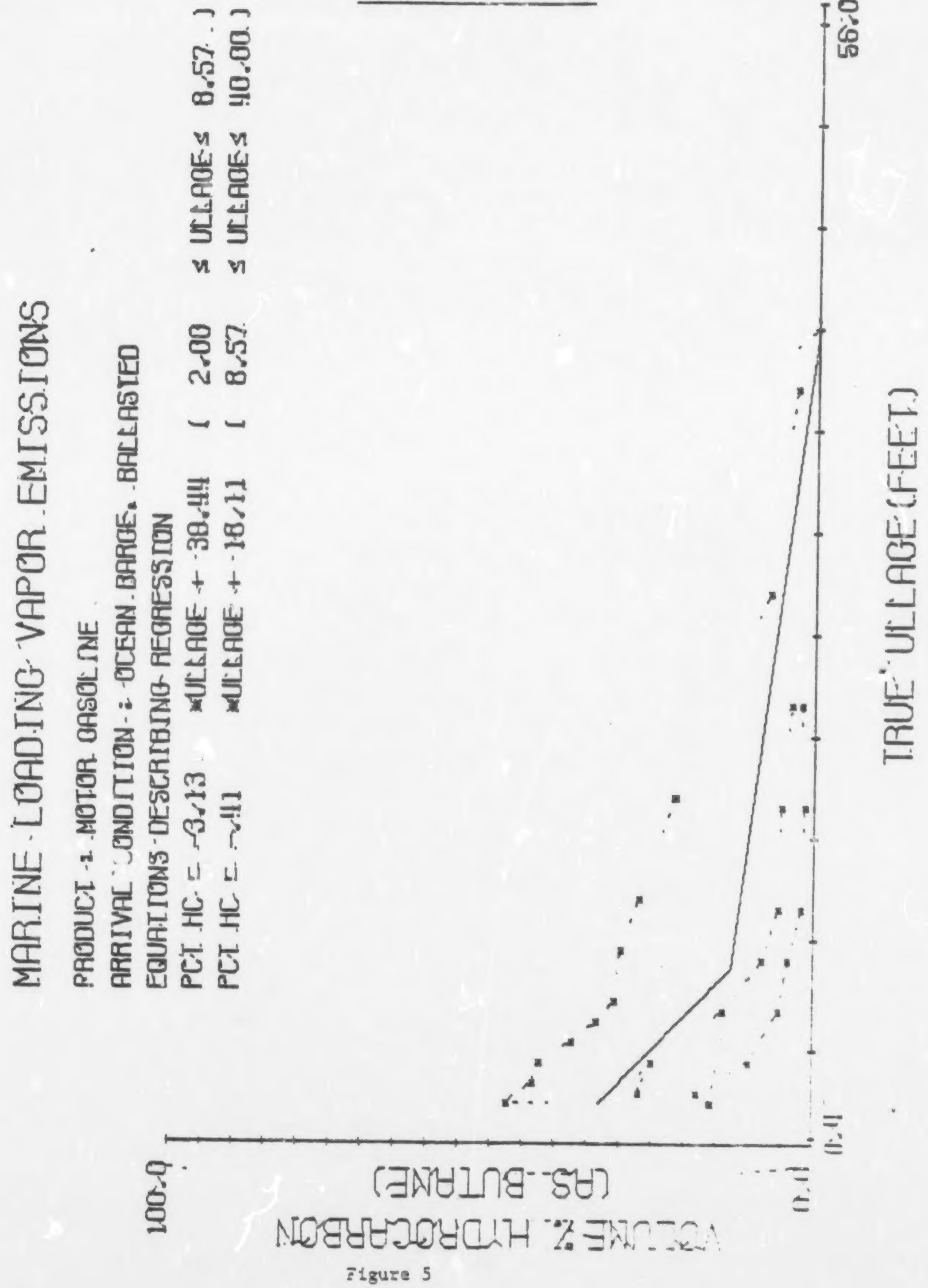

MARINE LOADING VAPOR EMISSIONS
PRODUCT : MOTOR GASOLINE
ARRIVAL CONDITION : OCEAN BARGE, BALLASTED
EQUATIONS DESCRIBING REGRESSION
PCT HC = -3.13 *ULLAGE + 38.44 (2.00 ≤ ULLAGE ≤ 8.57)
PCT HC = -.41 *ULLAGE + 18.11 (8.57 ≤ ULLAGE ≤ 40.00)
TRUE ULLAGE (FEET)
0.0
56.0
VOLUME % HYDROCARBON (AS BUTANE)
0.0
100.0

Figure 5

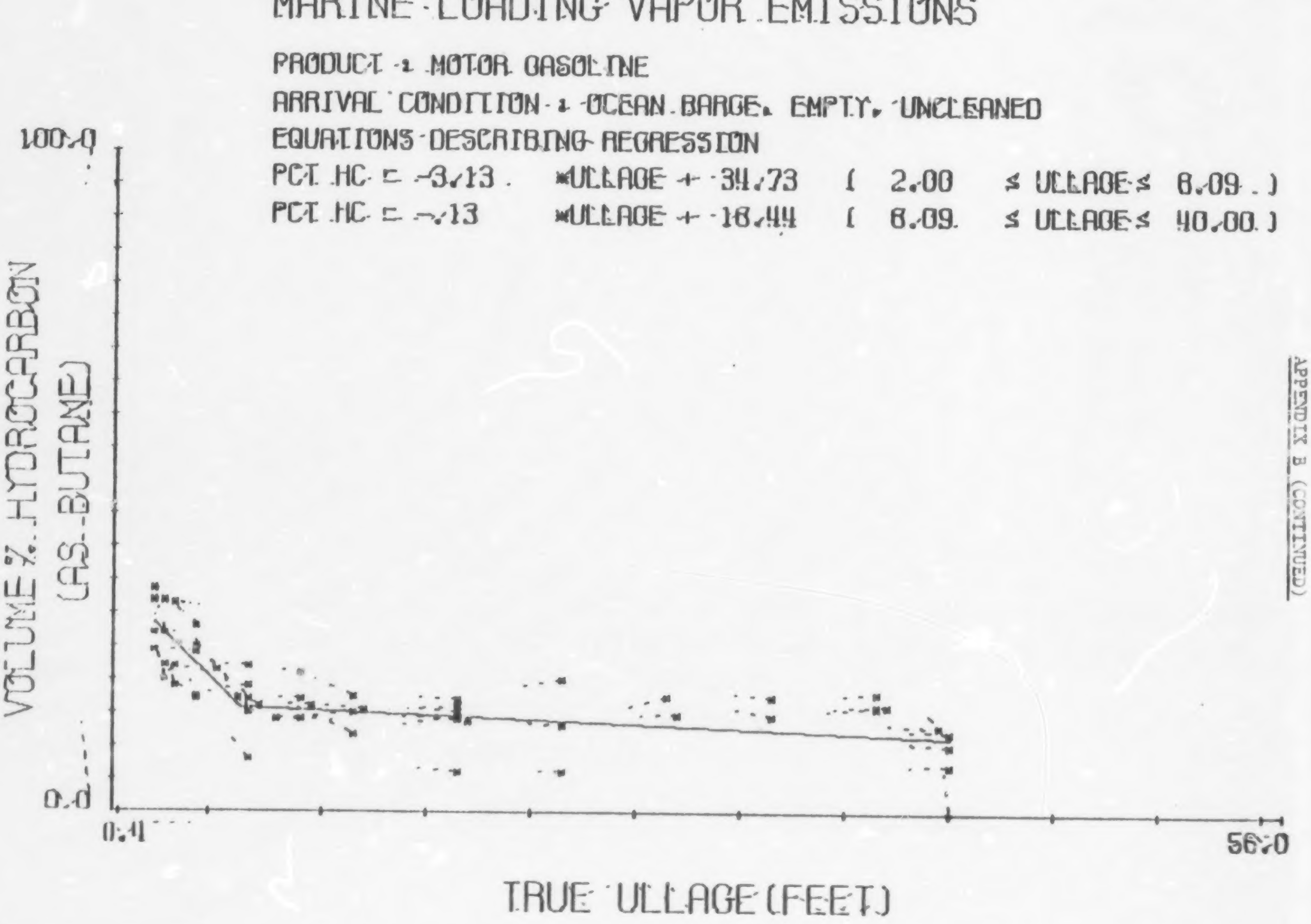

MARINE LOADING VAPOR EMISSIONS
PRODUCT : MOTOR GASOLINE
ARRIVAL CONDITION : OCEAN BARGE, EMPTY, UNCLEANED
EQUATIONS DESCRIBING REGRESSION
PCT. HC = -3.13 *ULLAGE + 34.73 (2.00 ≤ ULLAGE ≤ 8.09)
PCT. HC = -.13 *ULLAGE + 18.44 (8.09 ≤ ULLAGE ≤ 40.00)
100.0
0.0
0.41
56.0
VOLUME %. HYDROCARBON (AS BUTANE)
TRUE ULLAGE (FEET)

Figure 6

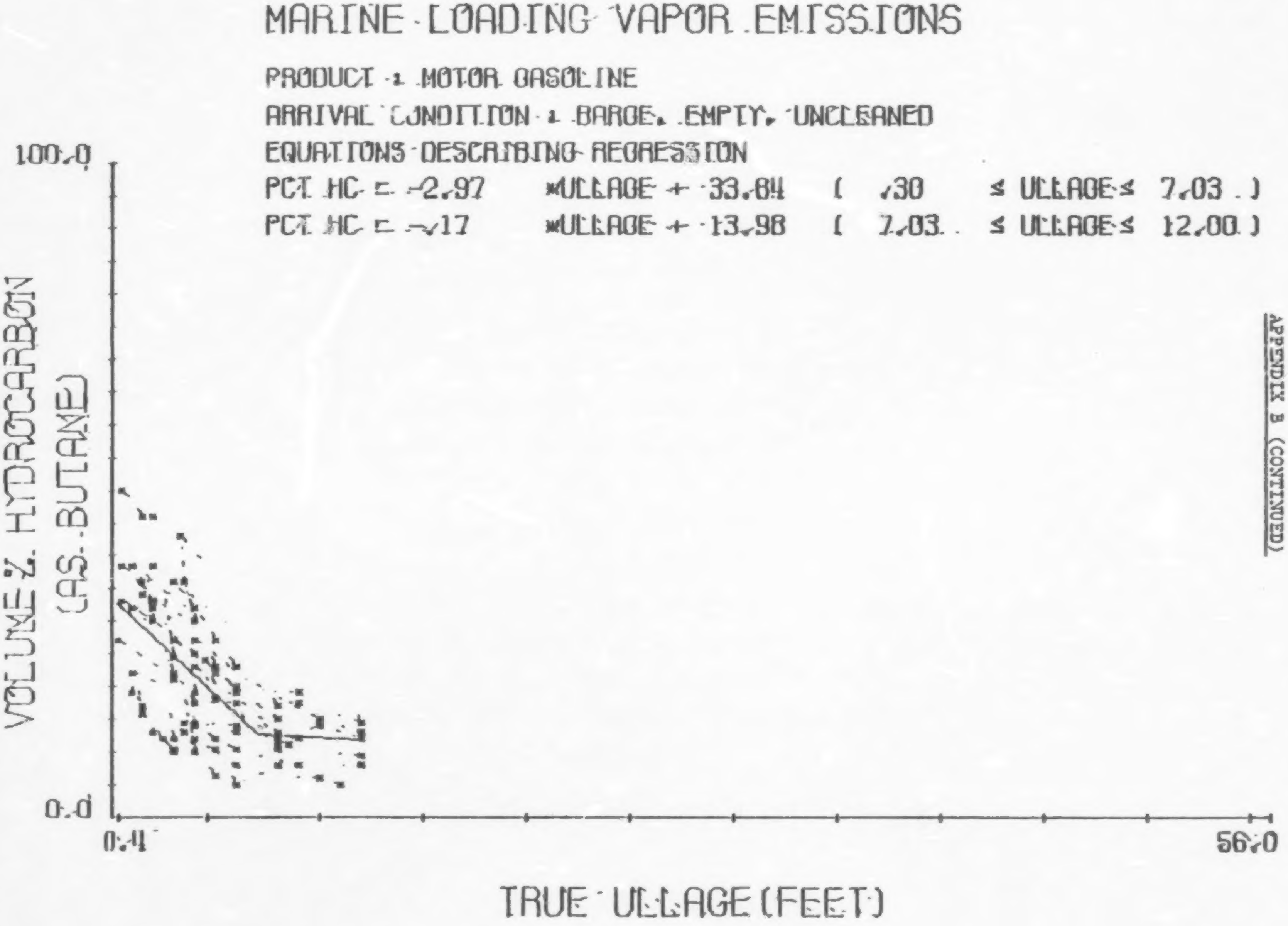

MARINE LOADING VAPOR EMISSIONS
PRODUCT : MOTOR GASOLINE
ARRIVAL CONDITION : BARGE, EMPTY, UNCLEANED
EQUATIONS DESCRIBING REGRESSION
PCT HC = -2.97 *ULLAGE + 33.84 (.30 ≤ ULLAGE ≤ 7.03)
PCT HC = -.17 *ULLAGE + 13.98 (7.03 ≤ ULLAGE ≤ 12.00)
100.0
0.0
VOLUME % HYDROCARBON (AS BUTANE)
0.41
56.0
TRUE ULLAGE (FEET)

Figure 7

MARINE LOADING VAPOR EMISSIONS

PRODUCT : AVIATION GASOLINE

ARRIVAL CONDITION : TANKER, EFFECTIVELY GAS FREED

EQUATIONS DESCRIBING REGRESSION

PCT HC = -1.91 *ULLAGE + 17.24 (1.00 ≤ ULLAGE ≤ 8.23)

PCT HC = -.04 *ULLAGE + 1.80 (8.23 ≤ ULLAGE ≤ 36.00)

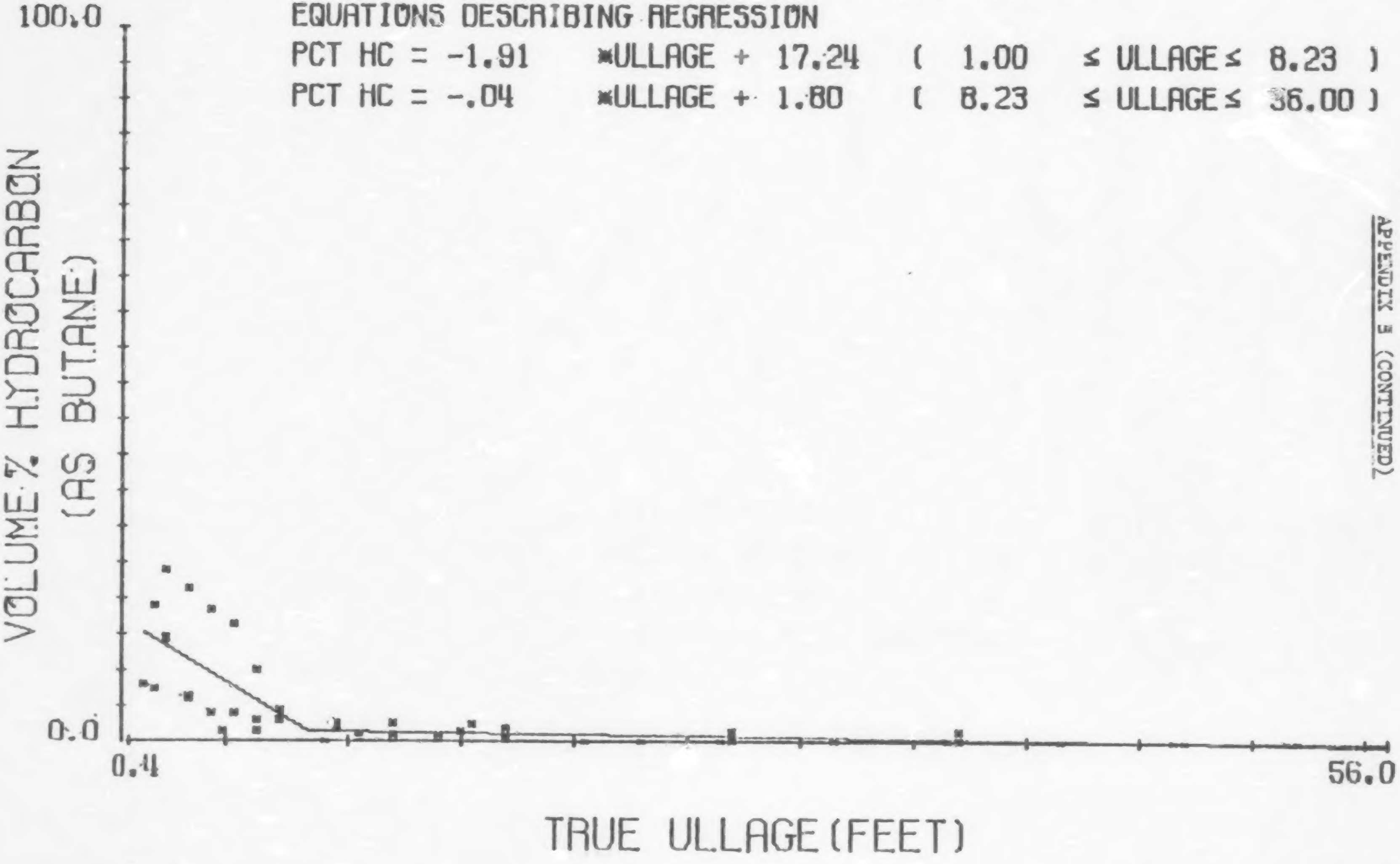
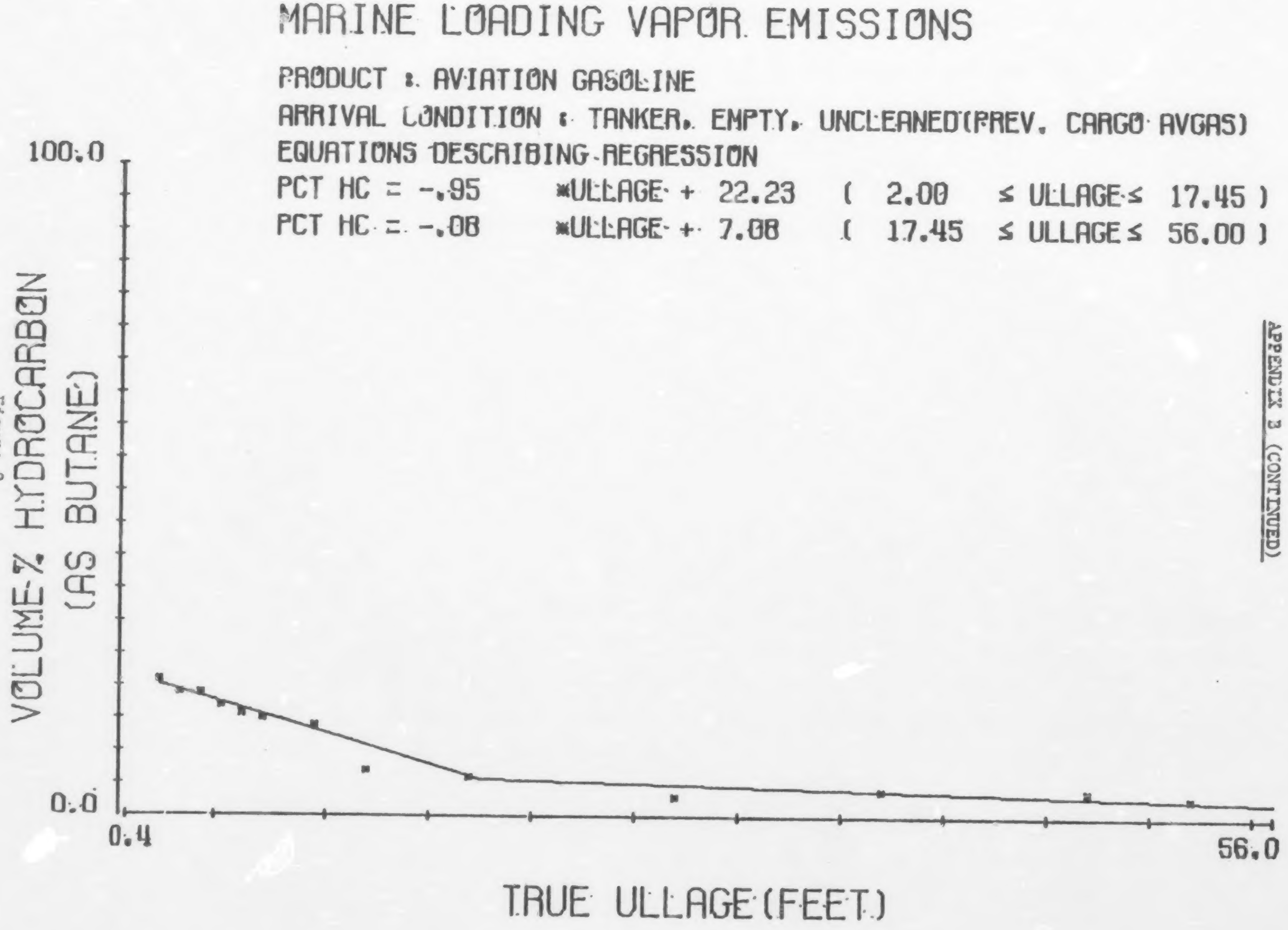


Figure 8



MARINE LOADING VAPOR EMISSIONS

PRODUCT : AVIATION GASOLINE

ARRIVAL CONDITION : TANKER, EMPTY, UNCLEANED(PREV. CARGO AVGAS)

EQUATIONS DESCRIBING REGRESSION

PCT HC = -.95 *ULLAGE + 22.23 (2.00 ≤ ULLAGE ≤ 17.45)

PCT HC = -.08 *ULLAGE + 7.08 (17.45 ≤ ULLAGE ≤ 56.00)

Figure 9

APPENDIX B (CONTINUED)

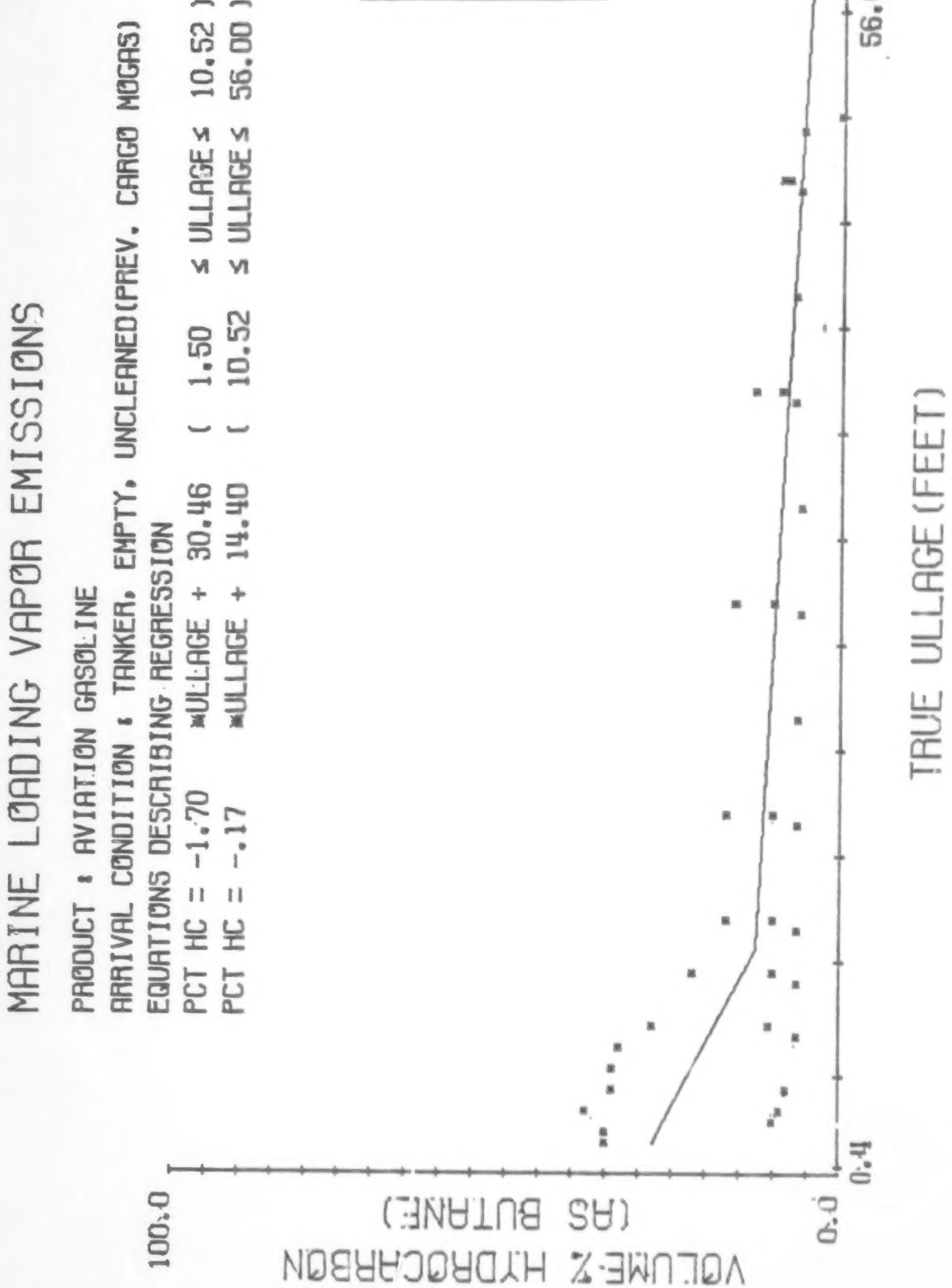
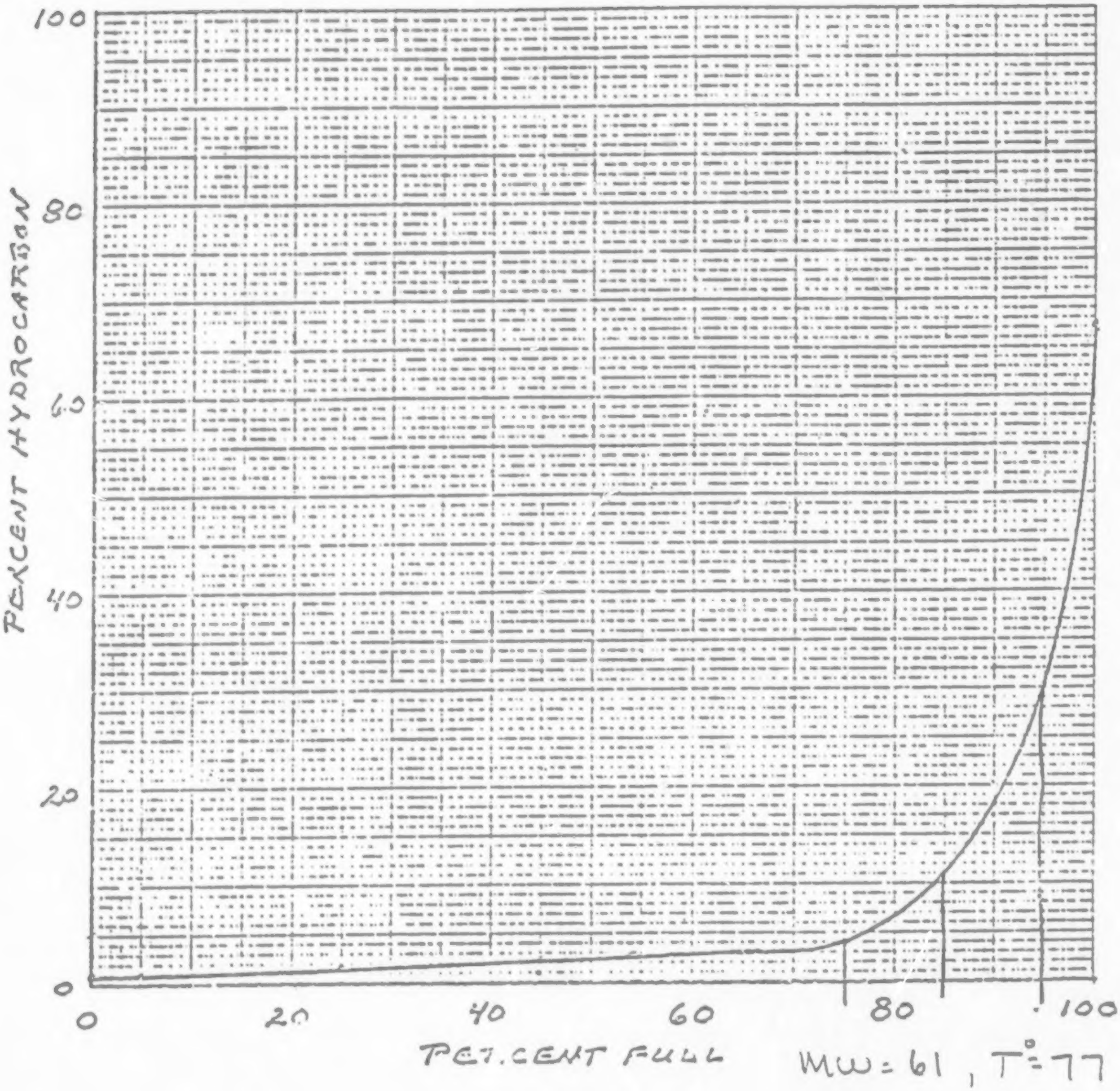


Figure 10

SHELL TEST RESULTS

(Reference 18)

S. S. VALLEY FORGE
COMPARTMENT 6S
10/19/74



MW = 61, T° = 77

FIG. 1

avg mole % = (.75)(2) + (.10)(7) + (.1)(18) + (.05)(44) =
= 1.5 + .7 + 1.8 + 2.2 = 6.2%

GASOLINE
12.0 RVP
77°F LIQ T.
4000 BBL/HR

$$E.F. = \frac{(1.8)(61)(6.2)}{(459+77)} = 1.2\ lb/10^3\ gal$$

536

S.S. VALLEY FORGE
COMPARTMENT 4S
10/19/74

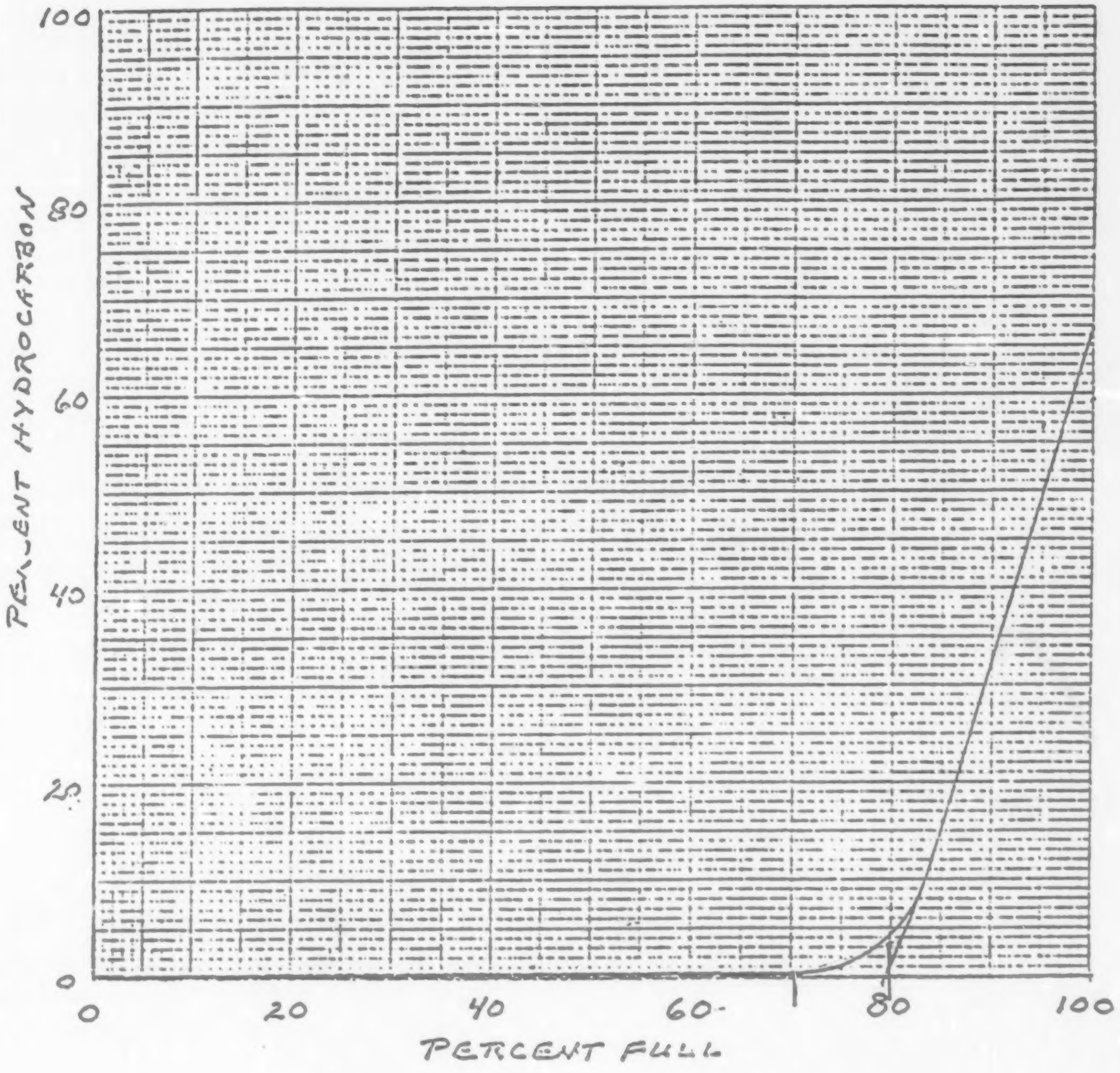


FIG. 2

GASOLINE
12.0 RVP
79°F LIQ T.
5600 BBL/HR

mol % = $(.7)(0) + (.1)(2) + (.2)(33) = (.2) + (6.6) = 6.8\ \%$

E.F. = $\dfrac{(1.83)(61)(6.8)}{(459+79)} = 1.4\ \text{lb}/10^3\ \text{gal}$

538

S. S. VALLEY FORGE
COMPARTMENT 1C
10/19/74

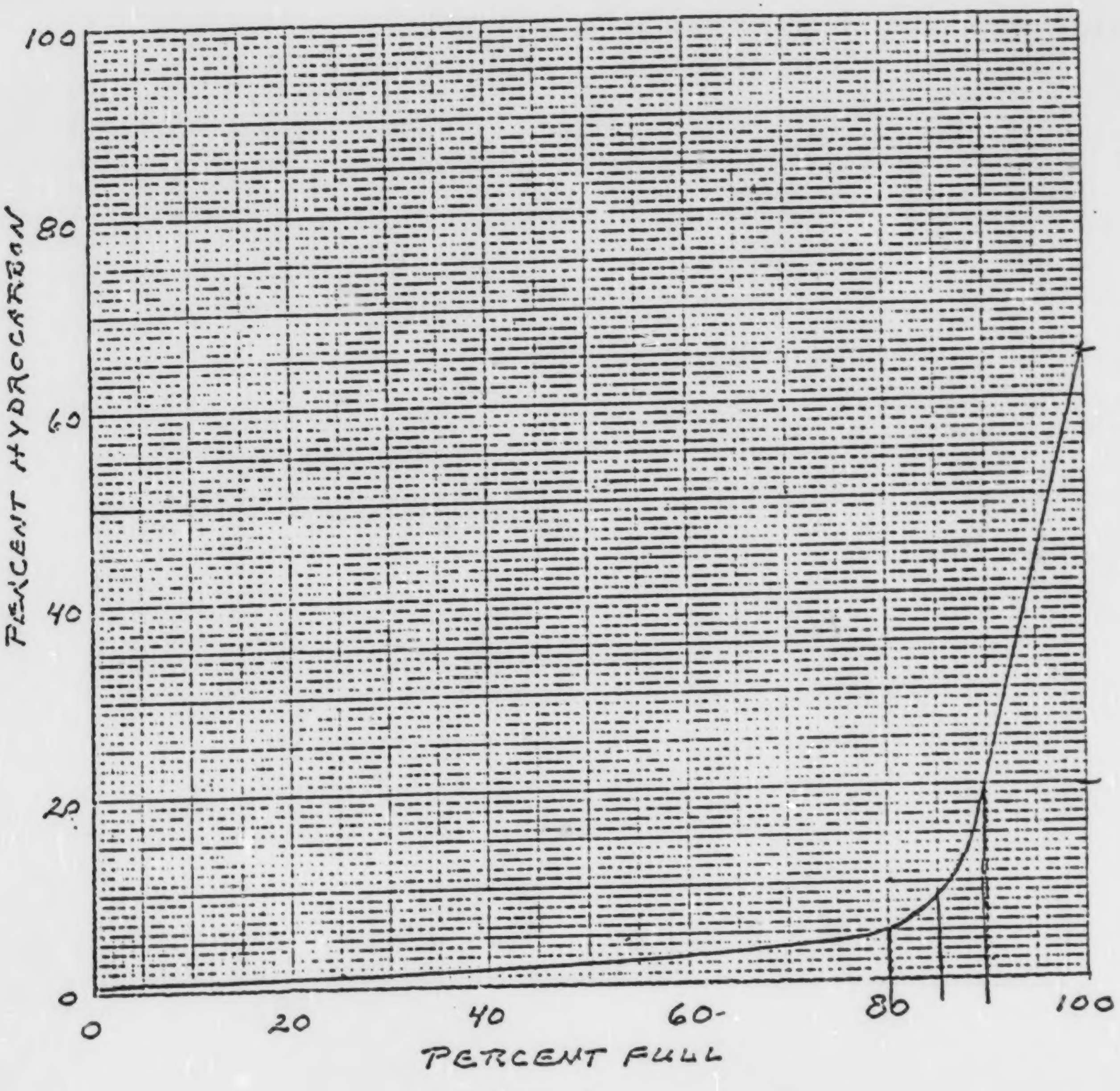


FIG 3

GASOLINE
13.5 RVP
77°F LIQ T.
6000 BBL/HR

mol % = (.8)(3) + (.05)(7) + (.05)(12) + (.1)(40) = 2.4 + .35 + .6
= 7.35%

$$E.F. = \frac{(1.83)(61)(7.35)}{536}$$

1.53 lb/10^3 gal

S. S. VALLEY FORGE
COMPARTMENT 6S
10/31/74

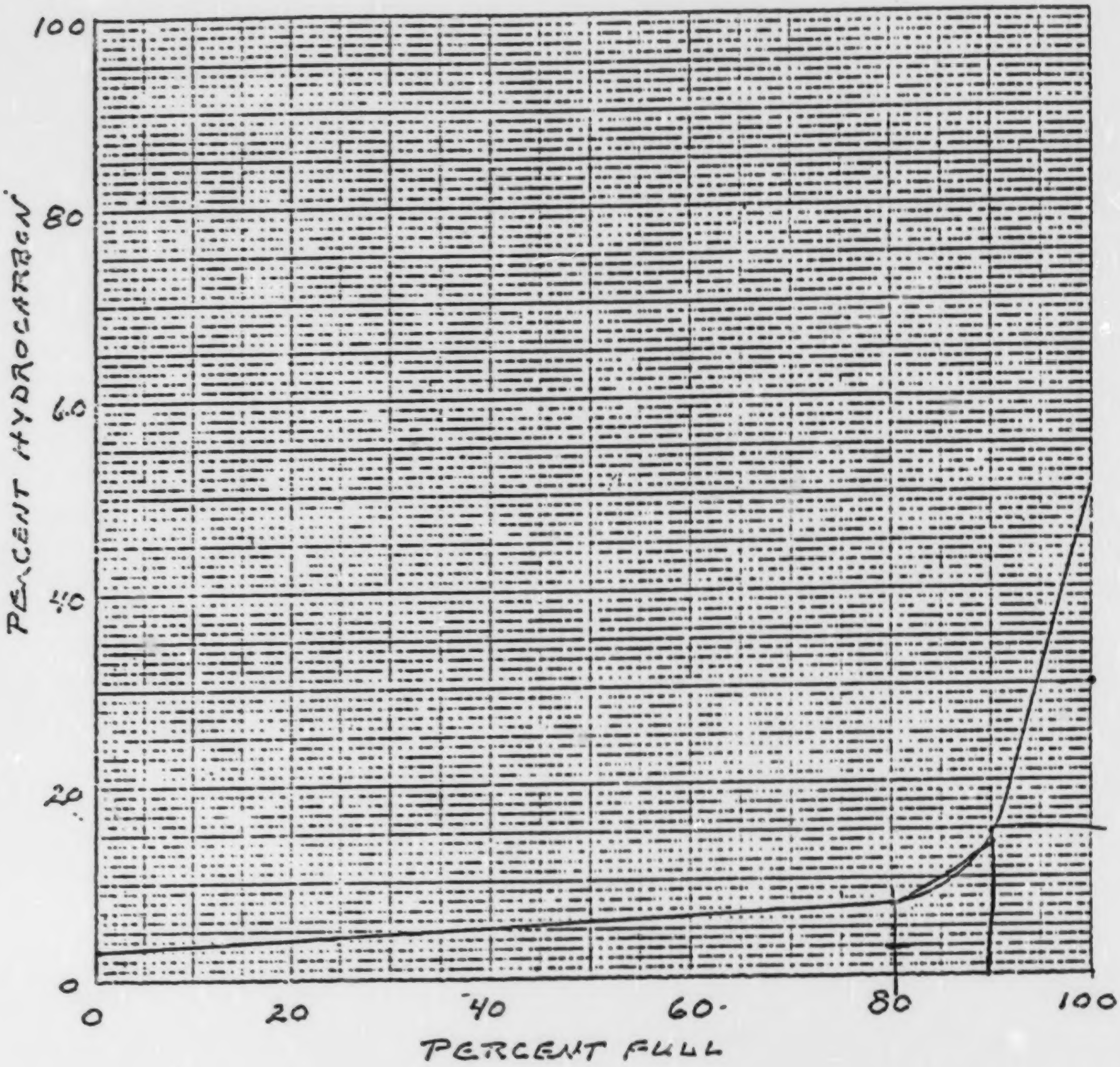


FIG 5

m%;

GASOLINE
12.0 RVP
75°F LIQ T.
5500 BBL/HR

Mol % = (5)(.80) + (10)(.1) + (30)(.1) = 4 + 1 + 3 = 8

$$\text{E.F.} = \frac{(1.83)(61)(8)}{534} = 1.67\ \text{lb}/10^3\text{gal}$$

S. S. VALLEY FORGE
COMPARTMENT 15 *
11/13/74

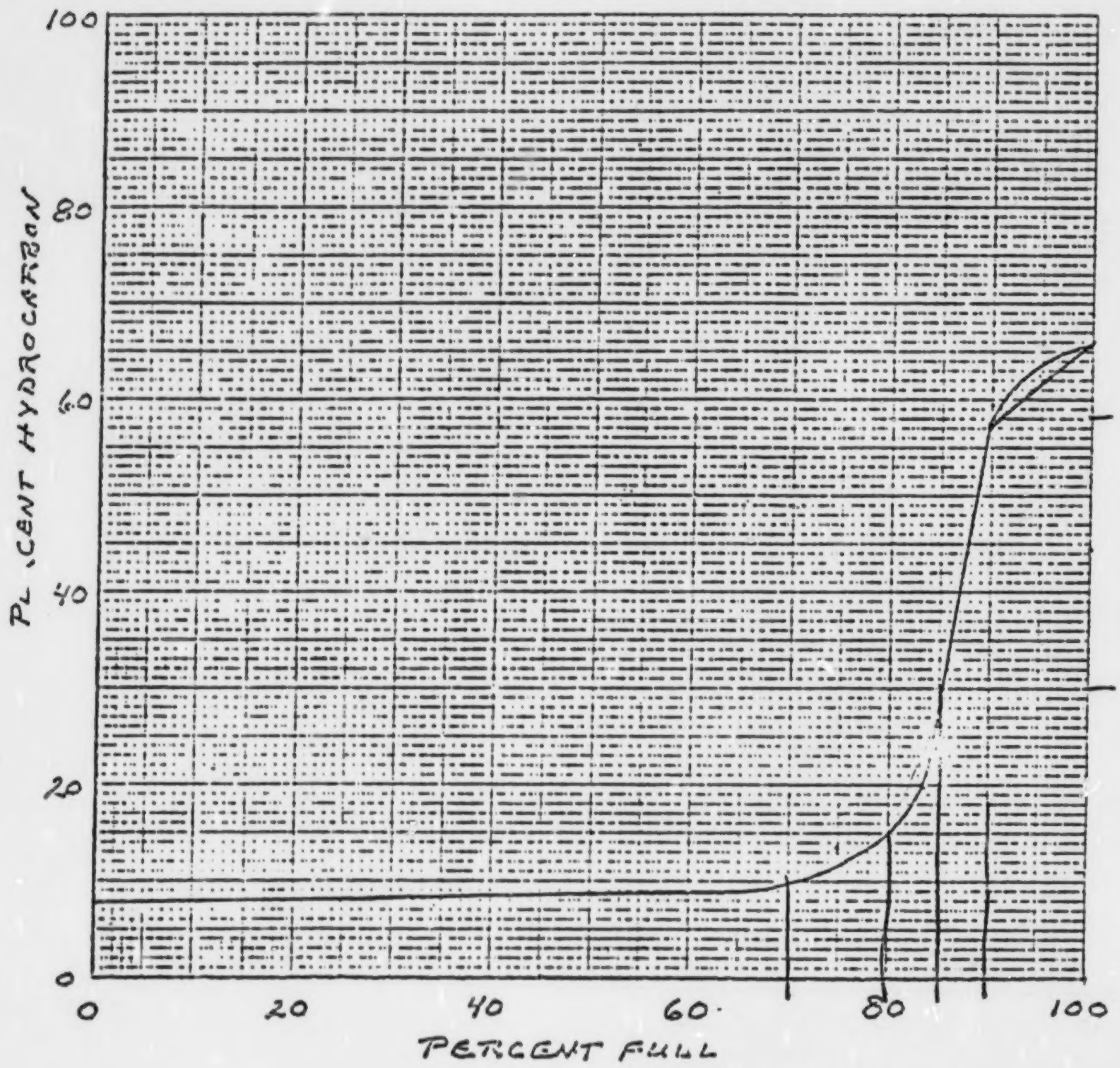


FIG 6

GASOLINE $\text{Mol\%} = (.7)(8.0) + (.1)(12) + (.05)(20) + (.05)(45) + (.1)(63) =$
13.3 RVP $5.6 + 1.2 + 1.0 + 2.3 + 6.3 = 16.4\%$ mol
54°F LIQ T
2000 BBL/HR $E.F = \frac{(1.83)(61)(16.4)}{513} = 3.57$ lb/1

* RETURNED AS UNLOADED - NO BALLAST, HOSING OR CLEANING

APPENDIX V

RADIAN EMISSION TESTING RESULTS

RADIAN EMISSION TESTING RESULTS

The figures in Appendix V graphically present the test data collected by Radian on hydrocarbon emissions from gasoline loading onto ships, barges, and ocean barges and on hydrocarbon emissions from crude ballasting. Sampling trip reports which detail the test procedures applied and the testing conditions are presented in Appendix VI.

FIGURE V-1

RADIAN TEST RESULTS

SHIP: SHELL - PASADENA

OPERATION: GASOLINE LOADING

TANK: 1C

PREVIOUS CARGO: KEROSINE-CLEANED

RVP: 10.2

DATE: 5/3/76

AVG HC CONCENTRATION: 3 VOL%

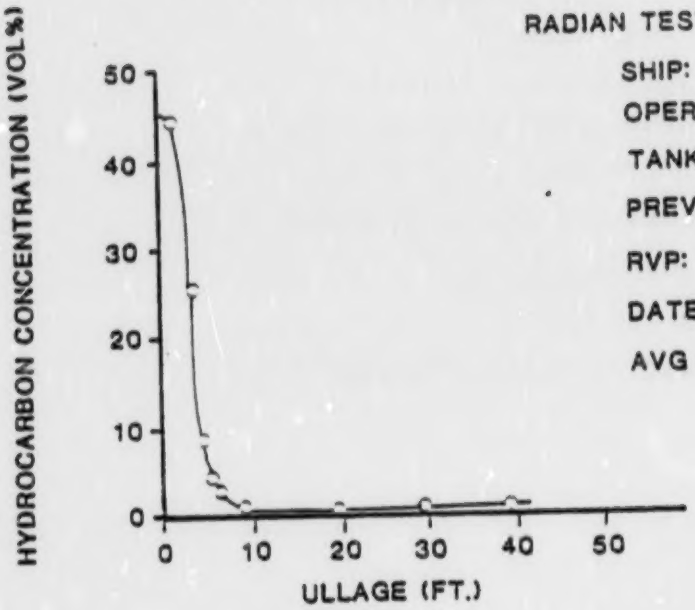


FIGURE V-2

RADIAN TEST RESULTS

SHIP: SHELL - PASADENA

OPERATION: GASOLINE LOADING

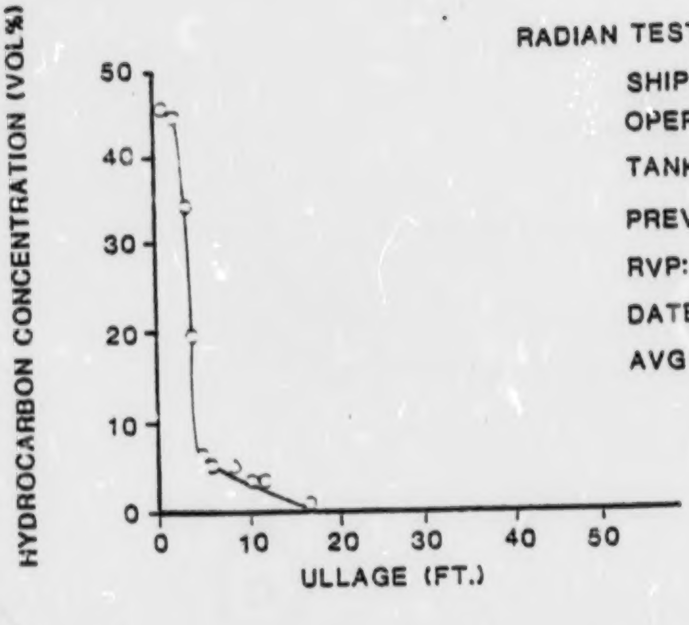
TANK: 7C

PREVIOUS CARGO: GASOLINE - CLEANED

RVP: 10.2

DATE: 5/3/76

AVG HC CONCENTRATION: 4.5 VOL%



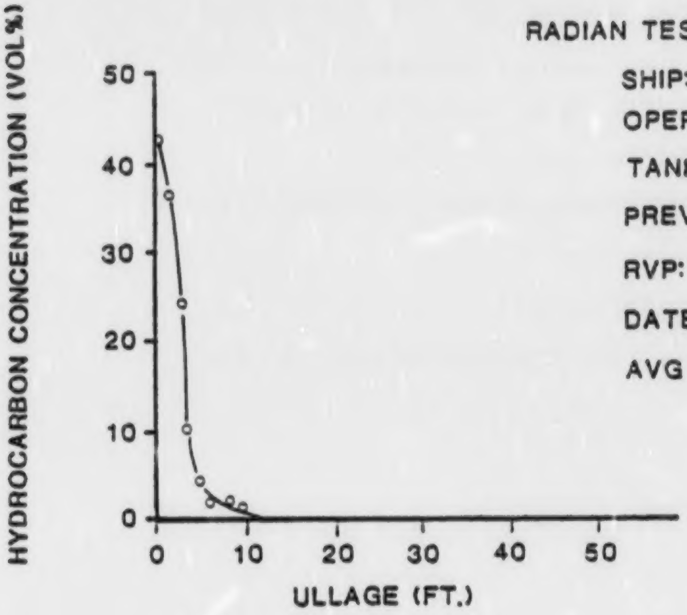


FIGURE V-3

RADIAN TEST RESULTS

SHIP: SHELL - PASADENA

OPERATION: GASOLINE LOADING

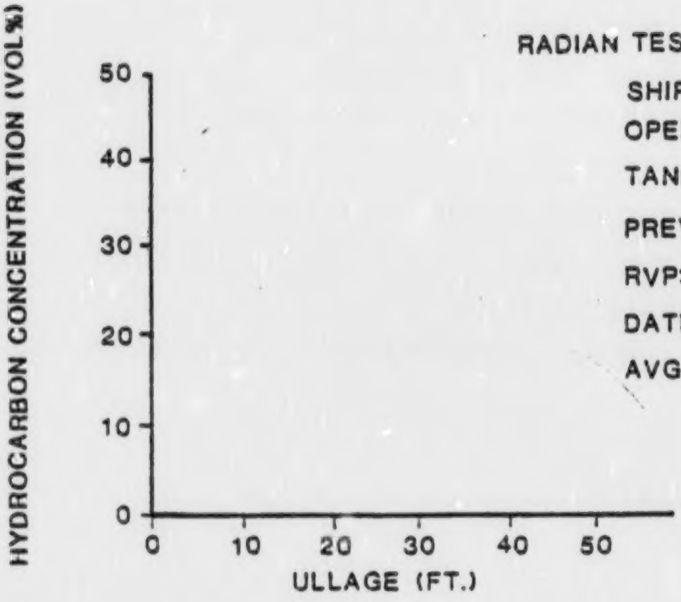
TANK: 7S

PREVIOUS CARGO: GASOLINE

RVP: 10.2

DATE: 5-3-76

AVG HC CONCENTRATION: 3 VOL. %



FIGURE

RADIAN TEST RESULTS

SHIP:

OPERATION:

TANK:

PREVIOUS CARGO:

RVP:

DATE:

AVG HC CONCENTRATION:

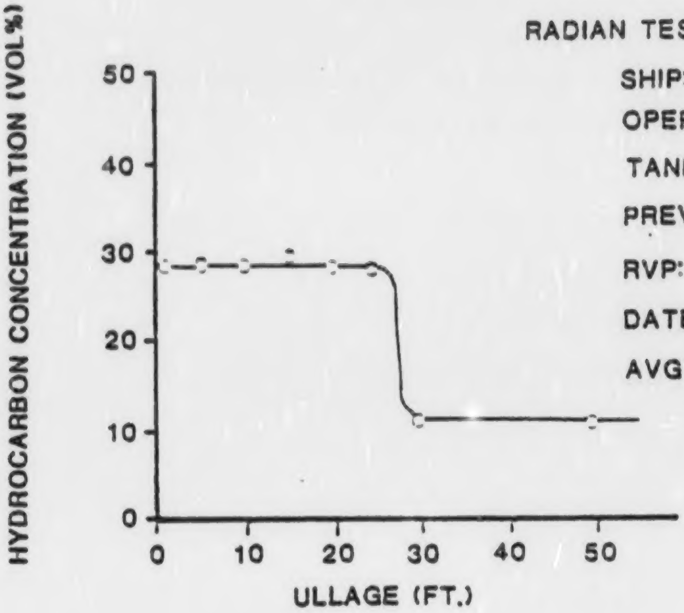


FIGURE V-4

RADIAN TEST RESULTS

SHIP: AMOCO - OCEAN CHALLENGER

OPERATION: BALLASTING

TANK: 6C

PREVIOUS CARGO: TRINIDAD CRUDE

RVP: 2.8 PSIA

DATE: 5/27/76

AVG HC CONCENTRATION: 20 VOL%

NOTE: THIS TANK ARRIVED ONLY 1/2 FULL

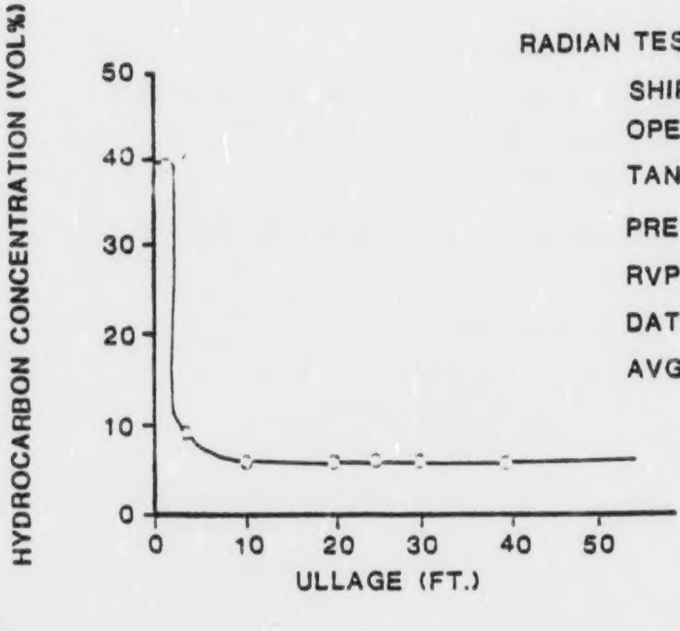


FIGURE V-5

RADIAN TEST RESULTS

SHIP: AMOCO - OCEAN CHALLENGER

OPERATION: BALLASTING

TANK: 4C

PREVIOUS CARGO: ESSIDER CRUDE

RVP: 6.4 PSIA

DATE: 5/27/76

AVG HC CONCENTRATION: 7 VOL%

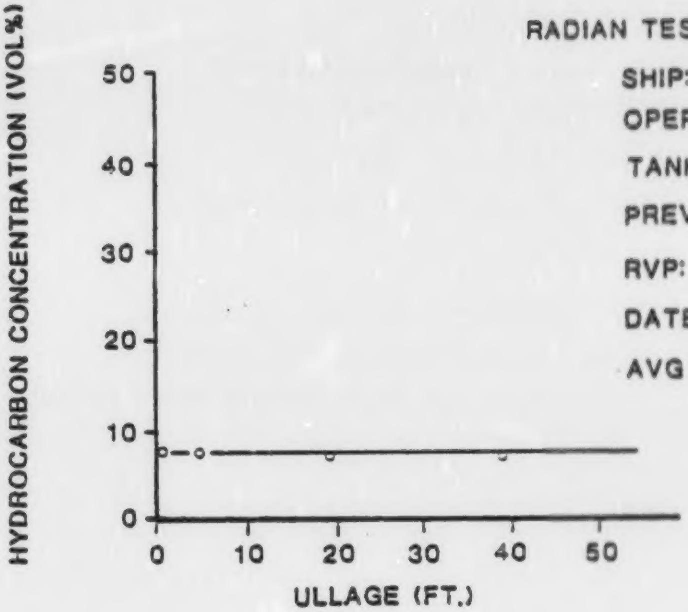


FIGURE V-6

RADIAN TEST RESULTS

SHIP: AMOCO - OCEAN CHALLENGER
OPERATION: BALLASTING
TANK: 3C
PREVIOUS CARGO: ESSIDER CRUDE
RVP: 6.4 PSIA
DATE: 5-27-76
AVG HC CONCENTRATION: 8 VOL. %

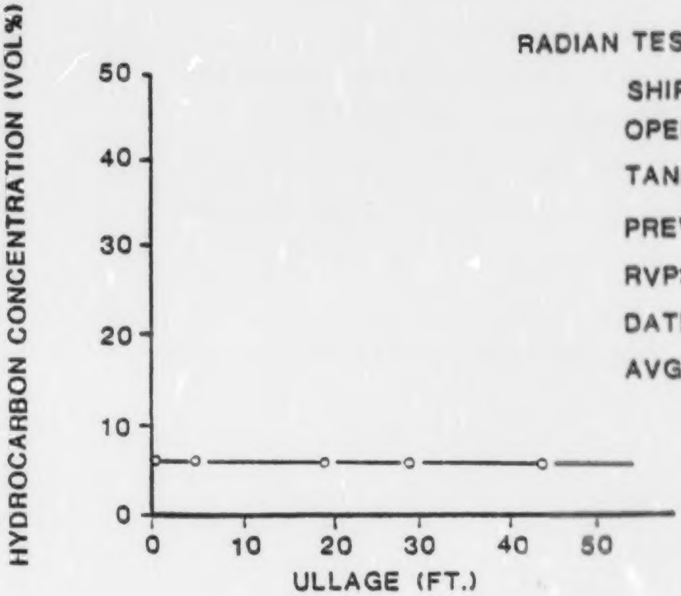


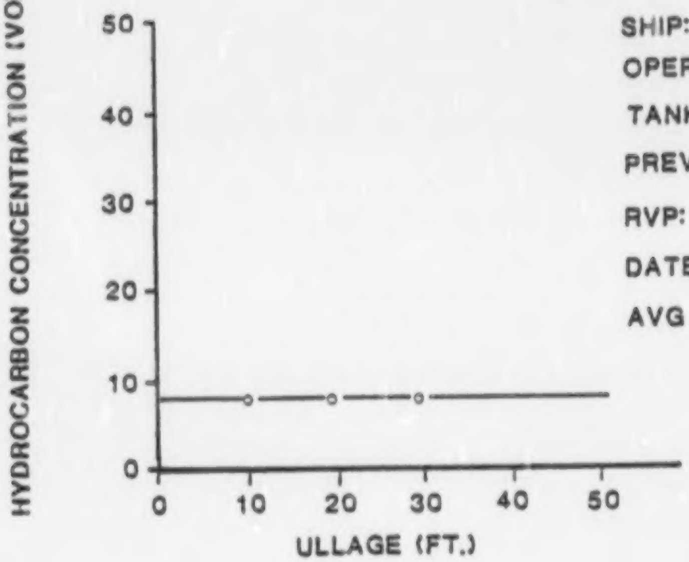
FIGURE V-7

RADIAN TEST RESULTS

SHIP: AMOCO - OCEAN CHALLENGER
OPERATION: BALLASTING
TANK: SP
PREVIOUS CARGO: TRINIDAD CRUDE
RVP: 2.8 PSIA
DATE: 5-27-76
AVG HC CONCENTRATION: 6 VOL. %

FIGURE V-8

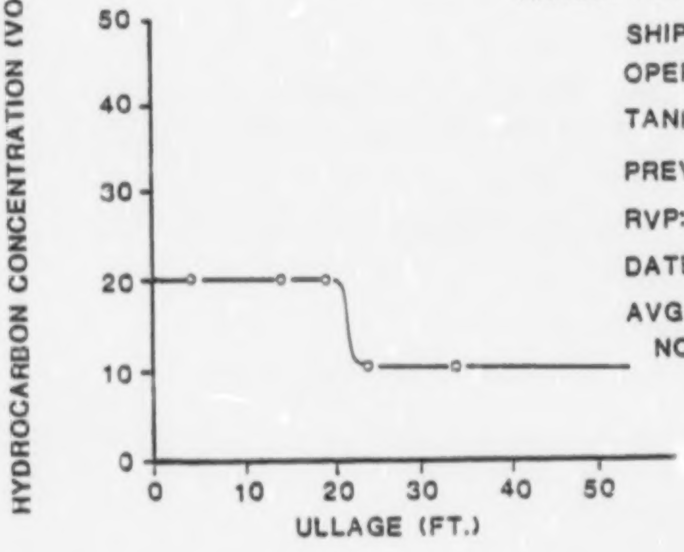
RADIAN TEST RESULTS



SHIP: AMOCO - OCEAN CHALLENGER
OPERATION: BALLASTING
TANK: 7C
PREVIOUS CARGO: TRINIDAD CRUDE
RVP: 2.8 PSIA
DATE: 5-27-76
AVG HC CONCENTRATION: 8 VOL. %

FIGURE V-9

RADIAN TEST RESULTS



SHIP: AMOCO - OCEAN CHALLENGER
OPERATION: BALLASTING
TANK: 10C
PREVIOUS CARGO: TRINIDAD CRUDE
RVP: 2.8 PSIA
DATE: 5-27-76
AVG HC CONCENTRATION: 14 VOL %

NOTE:
THIS TANK WAS USED TO COLLECT STRIPPINGS BEFORE THEY WERE PUMPED TO SHORE.

FIGURE V-10

RADIAN TEST RESULTS

SHIP: AMOCO-VIRGINIA

OPERATION: LOADING GASOLINE

TANK: 3C

PREVIOUS CARGO: DIESEL - CLEANED

RVP: 9.1

DATE: 5-28-76

AVG HC CONCENTRATION: 5 VOL. %

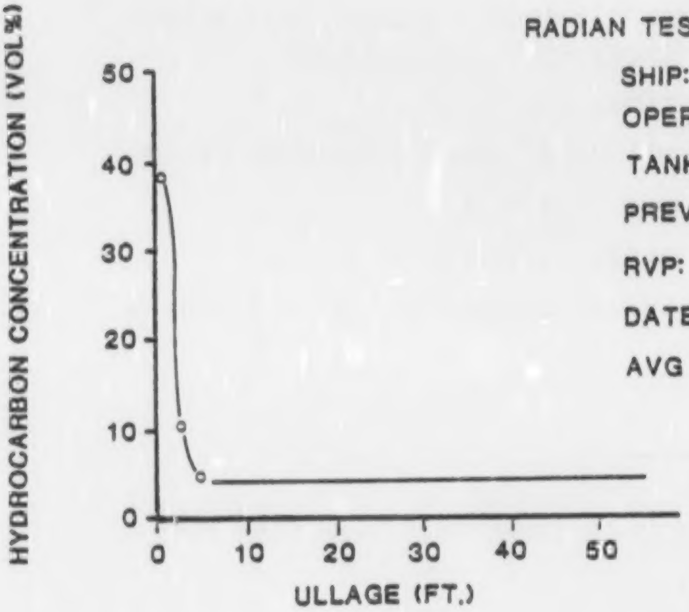


FIGURE V-11

RADIAN TEST RESULTS

SHIP: AMOCO - VIRGINIA

OPERATION: LOADING GASOLINE

TANK: 4C

PREVIOUS CARGO: GASOLINE - CLEANED

RVP: 11.1

DATE: 5-28-76

AVG HC CONCENTRATION: 4 VOL. %

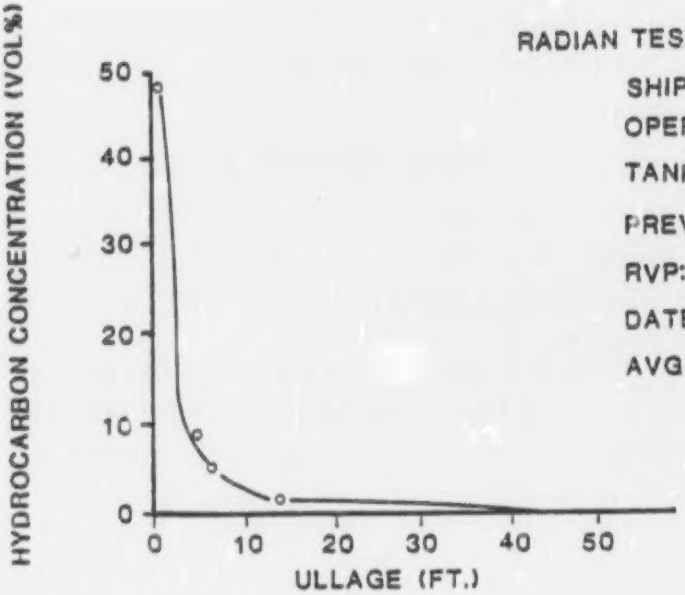
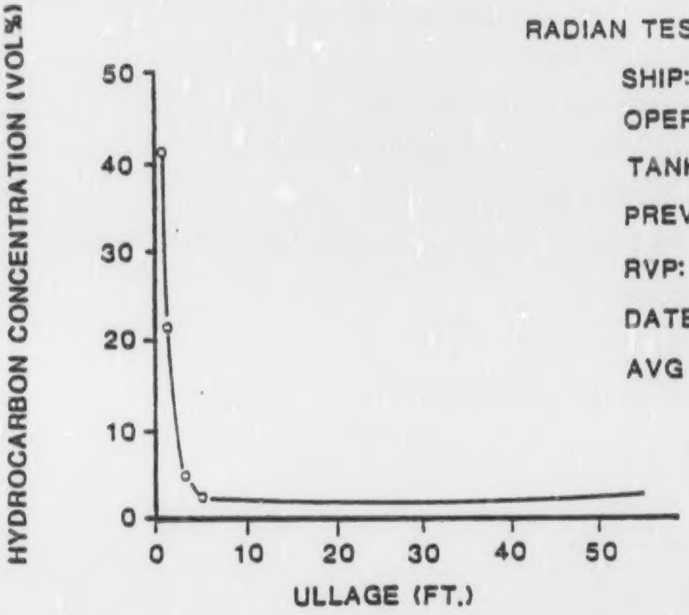


FIGURE V-12

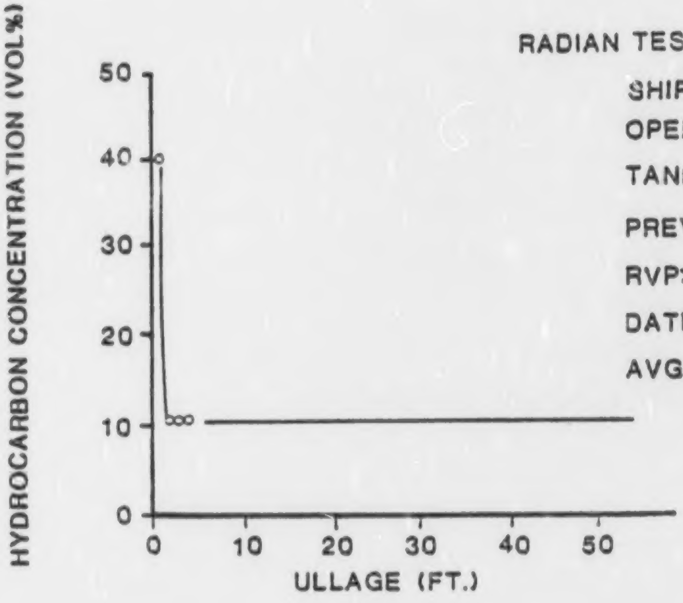
RADIAN TEST RESULTS



SHIP: AMOCO - VIRGINIA
OPERATION: LOADING GASOLINE
TANK: 4P
PREVIOUS CARGO: GASOLINE - CLEANED
RVP: 11.1
DATE: 5-28-76
AVG HC CONCENTRATION: 3 VOL. %

FIGURE V-13

RADIAN TEST RESULTS



SHIP: AMOCO - VIRGINIA
OPERATION: LOADING GASOLINE
TANK: 5C
PREVIOUS CARGO: GASOLINE - CLEANED
RVP: 11.1
DATE: 5-28-76
AVG HC CONCENTRATION: 10 VOL. %

FIGURE V-14

RADIAN TEST RESULTS

SHIP: AMOCO-VIRGINIA

OPERATION: LOADING GASOLINE

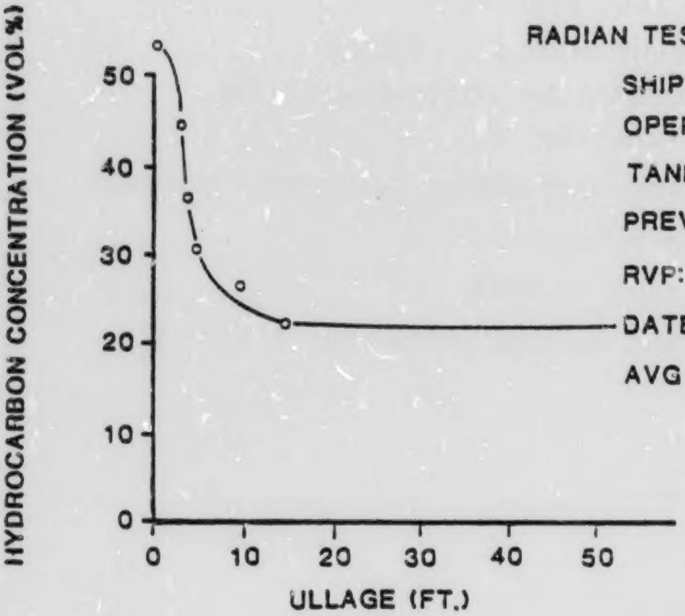
TANK: 8C

PREVIOUS CARGO: GASOLINE - UNCLEANED

RVP:

DATE: 5-28-76

AVG HC CONCENTRATION: 25 VOL. %



FIGURE

RADIAN TEST RESULTS

SHIP:

OPERATION:

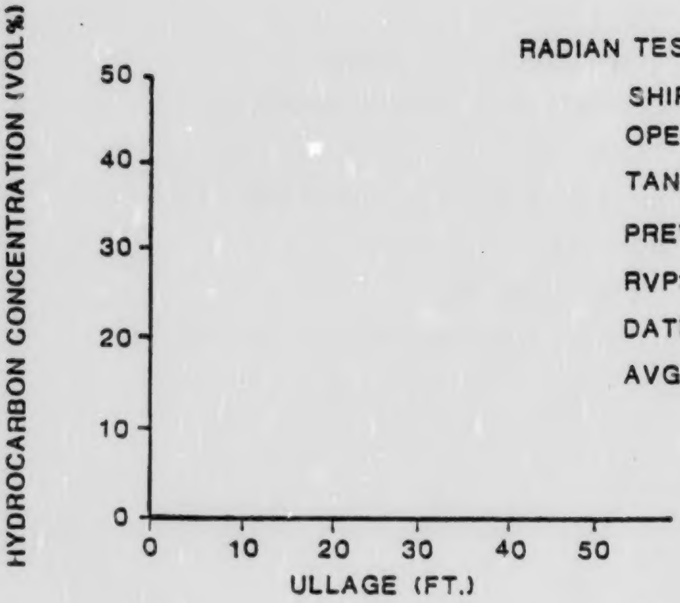
TANK:

PREVIOUS CARGO:

RVP:

DATE:

AVG HC CONCENTRATION:



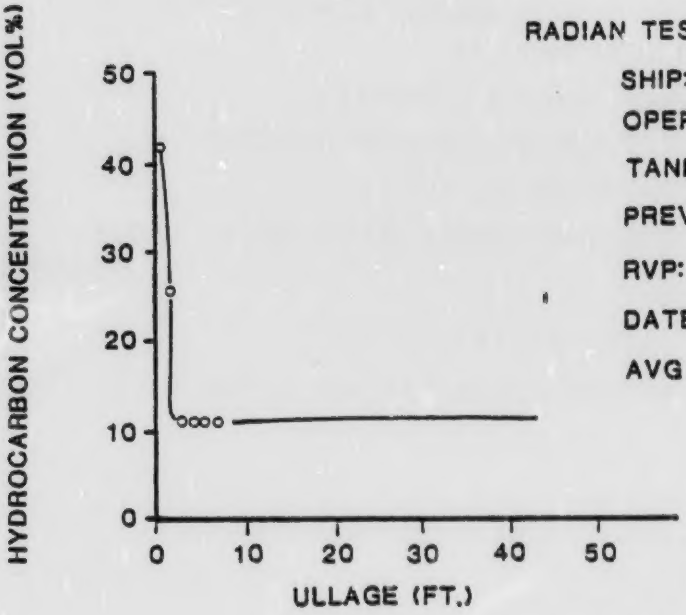


FIGURE V-15

RADIAN TEST RESULTS

SHIP: PORT EVERGLADES
OPERATION: GASOLINE LOADING
TANK: 1S
PREVIOUS CARGO: GASOLINE - BALLASTED
RVP:
DATE: 6-3-76
AVG HC CONCENTRATION: 11 VOL. %

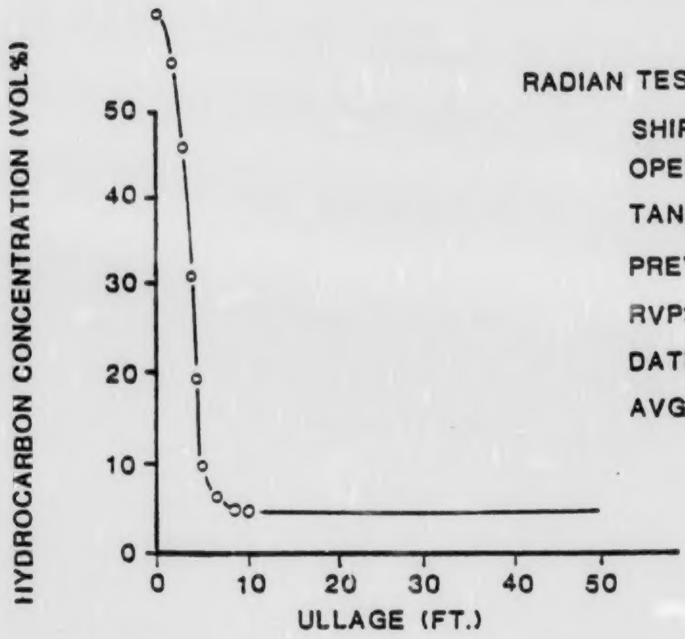


FIGURE V-16

RADIAN TEST RESULTS

SHIP: PORT EVERGLADES
OPERATION: GASOLINE LOADING
TANK: 3P
PREVIOUS CARGO: GASOLINE BALLASTED
RVP:
DATE: 6-3-76
AVG HC CONCENTRATION: 8.7 VOL. %

FIGURE V-17

RADIAN TEST RESULTS

SHIP: PORT EVERGLADES

OPERATION: GASOLINE LOADING

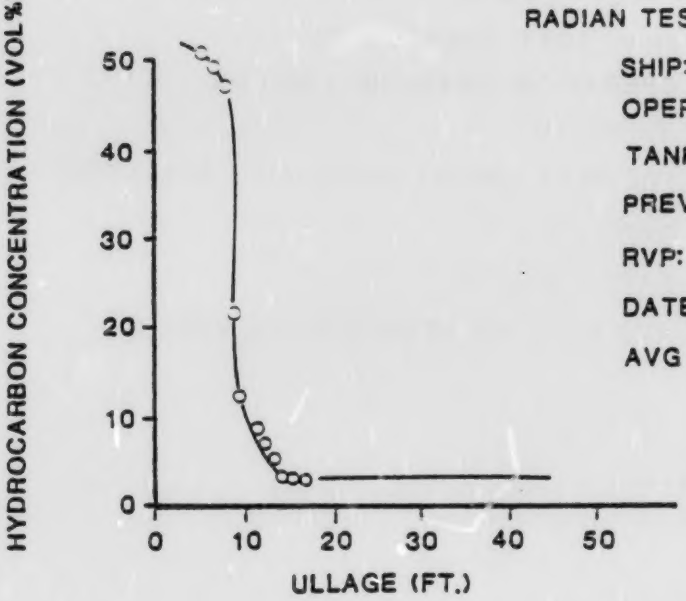
TANK: 3S

PREVIOUS CARGO: GASOLINE BALLASTED

RVP:

DATE: 6-3-76

AVG HC CONCENTRATION: 13 VOL. %



FIGURE

RADIAN TEST RESULTS

SHIP:

OPERATION:

TANK:

PREVIOUS CARGO:

RVP:

DATE:

AVG HC CONCENTRATION:

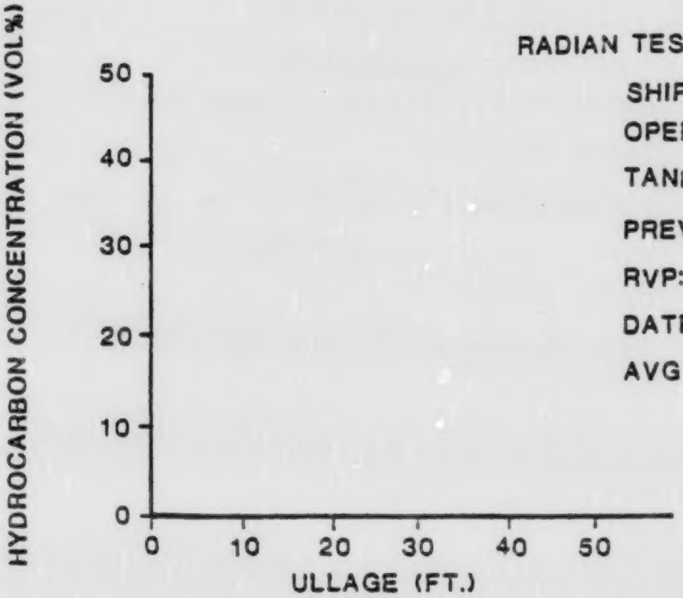
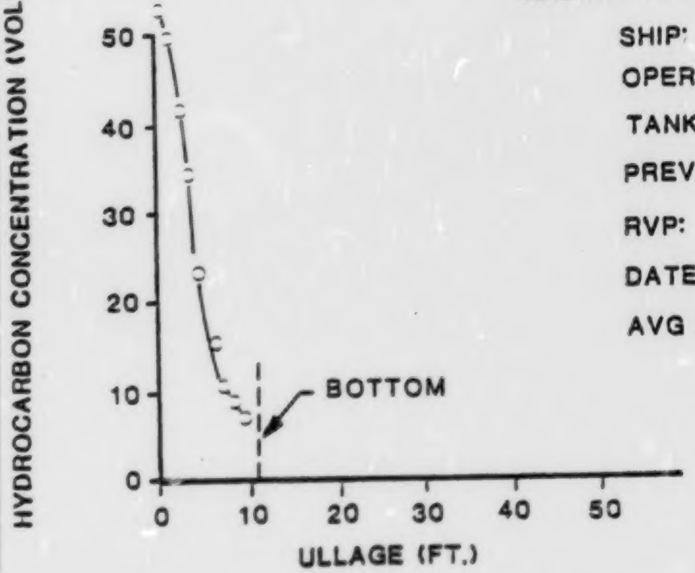


FIGURE V-18

RADIAN TEST RESULTS

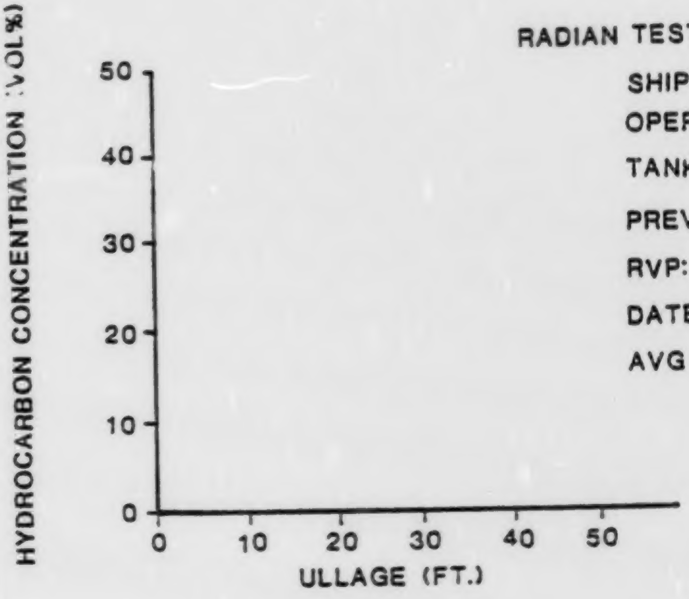
SHIP: EXXON BARGE 119
OPERATION: GASOLINE LOADING
TANK: 2P
PREVIOUS CARGO: GASOLINE - UNCLEANED
RVP:
DATE: 6-15-76
AVG HC CONCENTRATION: 27 VOL. %



FIGURE

RADIAN TEST RESULTS

SHIP:
OPERATION:
TANK:
PREVIOUS CARGO:
RVP:
DATE:
AVG HC CONCENTRATION:



APPENDIX VI

RADIAN EMISSION TEST DATA AND TRIP REPORTS

13 May 1976 Project No. 200-045-56
JDC:swm

MEMORANDUM

TO: Distribution
FROM: J. D. Colley
SUBJECT: Sampling trip to Shell, Deer Park; meeting notes with Exxon, Crown Central Petroleum, and Charter International Oil.

On May 3, Milton Owen and myself left for Houston to sample a gasoline loading operation at Shell's Deer Park marine facility. On May 4, we visited with Shell's Shipping Coordinator, Don Lanning, and toured the Shell tank farm and dock areas. Wednesday, May 5, we met with Lee Fuller, John Bentz, and Bruce Nichols of Exxon's Environmental Group and toured their terminal. Then on Thursday, we visited Crown (Bill Warnement) and Charter (Bill Miles) and inspected their marine facilities. The remainder of this memorandum summarizes the results of the testing at Shell and presents an outline of the meetings and tours between Radian and Shell, Exxon, Charter, and Crown personnel.

SHELL

Plans had been made with Shell Oil to sample the loading of Super Shell and Shell Regular into the tanker "Pasadena" on Tuesday, May 4. Monday morning Don Lanning notified Radian that the tanker was a day early and was expected to arrive at their docks by noon Monday. Milton Owen and I loaded the equipment and left for Deer Park as soon as possible. We arrived about an hour before the tanker was to be loaded and set up our equipment for testing.

After talking with the Chief Mate of the "Pasadena", Mr. Knox, we decided that it would be possible to sample the loading of three carge tanks with Super Shell (1C, 7C, and 7S). The test runs went smoothly and we sampled tank 1C beginning at 7:50 p.m. and finished with tank 7C at midnight. Although the data have not been fully processed at this time, a preliminary examination indicates a vapor concentration profile similar to that seen in the test results from the literature. The "Pasadena's" cargo tanks 1C, 7S, and 7C had a less than 1 percent uniform hydrocarbon concentration prior to the loading. The final hydrocarbon concentration was 43 percent for tank 7S; 45.5 percent for tank 1C; and 47 percent for tank 7C. The primary reason for the difference in the final vapor concentration is thought to be the loading rates. Tank 7S was loaded the fastest, while tanks 7C and 1C took over twice as long to load.

The RVP of the gasoline was 10.2 psi and its initial loading temperature was 73°F.

Tuesday, Milt and I met with Don Lanning, Shell's Shipping Coordinator. He showed us around the Shell tank farm and the dock site. We discussed with him the dockside equipment at their terminal and the operating procedures there. We traced with him to path of the Shell gasolines from storage to blending to pumping of the product either to the bulk pipeline or to the marine dock. The pumps which deliver the gasoline to the docks are located within the tank farm area. These pumps are of the centrifugal type and they can deliver gasoline at the rate of nearly 6,000 barrels per hour each. They operate at 150 psi.

At the terminal itself, there are four docks either of which they can each load gasoline. Also, the Shell refinery receives approximately one-half of its crude oil from ships and barges.

Mr. Lanning indicated that approximately twelve tankers are chartered by Shell to serve the Deer Park refinery on a regular basis. The collection system for Shell's proposed vapor recovery unit will consist of flexible hoses which would transfer the vented gasoline vapors from these ships to four recovery units located next to each of the four docks. He claimed that the system has been designed to be compatible with the Exxon ships which must mate with the Exxon vapor recovery system. He said the two systems are somewhat different. Mr. Lanning agreed to supply a rough schematic of the piping which transfers gasoline to the docks from the refinery and crude oil from the docks to the tank farm. Additional information concerning Shell's marine terminals (which will be supplied to Radian by Shell personnel in the near future) will describe the facility and the operations in more detail.

In summary, this sampling visit and tour should be very valuable in completing the program. The data we gathered on the loading operation appear to agree with data observed from past tests by other companies. Shell's Deer Park marine facility is one of the largest of its kind. The sampling and tour along with further cooperation by Shell personnel in providing Radian with more detailed information on their terminal will go a long way toward achieving the objectives of this program.

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet I
Survey of Shore-Side Information

General Information

Date May 3, 1976
Name of vessel S.S. Pasadena
Terminal Shell Deer Park Mfg Complex
Product(s) loaded Super Shell Motor Gasoline

Terminal Information

Storage tank number
Storage tank size
Type of roof
Length of time stored
Tank color; age ,
Storage temperature
Pump type Centrifugal
Pump size
Pump nominal rate appr. 5,000 bbl/hr

Ambient Conditions

Air temperature 65 - 70 °F
Weather conditions Clear to partly cloudy, 5-10 mph wind

Prepared by: David Colley

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet II

Survey of Vessel Information

General Information

Date May 3, 1976

Name of vessel S.S. Pasadena

Type of vessel: ship ✓ barge ____

Total number of cargo tanks 24

Vessel size (DWT) 35,000

Prior Cargo Information

Prior cargo Gasoline in 7C & 7S; Jet A (Kerosine) in 1C.

Prior cargo RVP ____

Where unloaded ____

Date unloaded ____

Does cargo tank have stripper lines yes

Vessel In-Transit Conditions

Type cleaning and/or ballasting for each tank All tanks were vapor-freed by butterworthing ~~and~~ or ballasting followed by blow drying.

Open or closed hatches ____

Ratings on PV valve 0.5 psi Vac., 2.5 psi pressure

Time at sea ____

Prepared by: David Colley

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet III

Recorded Data

Date May 3, 1976　　Product Loaded Super Shell, RVP=10.2

Cargo Tank No 1C　　Loading Rate 4,300 bbl/hr

I. Hydrocarbon Profile Prior to Loading

	% LEL	% Gas
Bottom	4	<1
Middle	4	<1
Top (deck level)	4	<1

II. Vapor Blanket Depth

A. At Lower Level of Tank

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)

B. At Upper Level of Tank

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet III

Recorded Data

Date May 3, 1976 Product Loaded Super Shell, RVP = 10.2

Cargo Tank No 7C Loading Rate Varied from 4500 to 7400 bbl/hr

I. Hydrocarbon Profile Prior to Loading

	% LEL	% Gas
Bottom	4	≤1
Middle	4	≤1
Top (deck level)	4	≤1

II. Vapor Blanket Depth

A. At Lower Level of Tank

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)

B. At Upper Level of Tank

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet III

Recorded Data

Date May 3 1976　Product Loaded Super Shell, RVP=10.2

Cargo Tank No 7S　Loading Rate 2750 bbl/hr

I. Hydrocarbon Profile Prior to Loading

	% LEL	% Gas
Bottom	4	<1
Middle	4	<1
Top (deck level)	4	<1

II. Vapor Blanket Depth

A. At Lower Level of Tank

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)

B. At Upper Level of Tank

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet III (Cont.)

Recorded Data

Date May 3, 1976

Product Loaded Super Shell RVP=10.2

Cargo Tank No 1C

Loading Rate 4300 bbl/hr

III. Hydrocarbon Concentration on Vented Vapors

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T (°F)
[illegible]	Empty				
	55				
1750	~~50~~ 48'6"	3	<1	99	73°F
1800	45	3	<1	99	
1820	40	2	<1	99	
1845	35	2	<1	98	
1908	30	2	<1	96	
1930	25	2	<1	96	
1950	20	2	<1	91	
2000	18	2	<1	90	
2008	16	3	<1	90	
2016	14	7	<1	88	
2025	12	12	<1	87	
2035	10	14	2	86	
2038	9	27	2	85	
2043	8	76	4	84	
2048	7	>100	9	84	
2052	6		26	83	
2056	5		43	83	
Ullage → 2058	4'6"		45.5	83	
	3				
	2				
	1				

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet III (Cont.)

Recorded Data

Date May 3, 1976
Cargo Tank No 7C
Product Loaded Super Shell, RVP=10.2
Loading Rate Varied from 4500 to 7400 bbl/hr

III. Hydrocarbon Concentration on Vented Vapors

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T (°F)
	Empty				
	55				
	50				
	45				
	40				
	35				
	30				
	25				
2110	20	12	<1	84	
2120	17	15	<1	79	
2330	15	85	3	71	
2337	13	87	3	72	
2343	11	90	5	72	
	10			~~73~~	
2348	9	>100	5	73	
2350	8		7	74	
2354	7		20	75	
2356	6		35	75	
2400	5		46	75	
2401	4'6"		47	75	78
	3				
	2				
	1				

d 7C
ived into
P

l Ullage

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet III (Cont.)

Recorded Data

Date May 3, 1976

Product Loaded Super Shell, RVP = 10.2

Cargo Tank No 7S

Loading Rate 2750 bbl/hr

III. Hydrocarbon Concentration on Vented Vapors

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T (°F)
	Empty				
	55				
	50				
	45				
	40				
	35				
2212	30	7	<1	77	
2225	25	11	<1	77	
2240	20	14	1	76	
	18				
2255	15	24	1	75	
2302	13	25	1	74	
2313	11	34	2	74	
	10				
2315	9	46	2	73	
2317	8	>100	4	73	
2321	7		10	73	
2324	6		24	73	
2325	5		37	73	
2327	4'6"		43	73	77
	3				
	2				
	1				

21 June 1976

MEMORANDUM

TO: Distribution

FROM: J. D. Colley

SUBJECT: Trip Report - AMOCO Oil Company, Texas City, Texas
May 26-28, 1976

I. Purpose

The purpose of this trip was to measure and record the hydrocarbon emissions from the ballasting of a crude oil tanker and the loading of gasoline onto a tanker at AMOCO Oil Company docks and Marathon Oil Company docks in Texas City, Texas.

II. Place and Date

AMOCO Texas City refinery marine dock No. 40, May 27 (crude ballasting); AMOCO dock No. 32, May 28 (gasoline loading); and Marathon dock No. 22, May 28 (gasoline loading).

III. Attendees

AMOCO: Captain Larkin
Captain Park (M/V Ocean Challenger)
Captain Skibba (S.S. AMOCO Virginia)
Bill Bulger, N.Y. Office (M/V Ocean Challenger)
Howard Husa, Engineer
Jim Ross

Radian: David Colley
Clint Burklin

EPA: Bill Polglase, ESED

IV. Discussion

A. M/V Ocean Challenger

The M/V Ocean Challenger is a Class A tanker of approximately 53,000 DWT. It is owned by AMOCO Petroleum Corporation, has a Korean crew, and sails under the Liberian flag. Currently the ship is in service between the Caribbean and the AMOCO Texas City refinery. On this particular voyage, the ship had arrived at Dock 40, a dock used exclusively by AMOCO to handle crude oil, on Tuesday May 25, to unload Trinidad (Galeota crude-RVP 2.8) and Essider (Lybian crude-RVP 6.4). The average unloading rate was approximately 14,000 barrels per hour. The tanker had nine center tanks and seven port and starboard wing tanks.

Prior to taking hydrocarbon measurements on the tanker's ballasting operation, a meeting was held with Captain Park and his first mate to discuss the purpose of our visit. Communication was difficult with them, however, we determined that 40 percent of the ship's capacity would be ballasted and we obtained a ballasting diagram showing the final ullage of each tank to be ballasted. From this information a preliminary sampling strategy was decided upon. Data was to be taken on the hydrocarbon concentration profile of as many tanks as possible prior to ballasting. Then the probe would be positioned near the open ullage hatch and the vented vapor concentrations recorded for a selected tank.

At 4:00 a.m. all the crude oil had been discharged from the tanks. We began taking measurements at this time with our MSA Gascope, Model 53. Simultaneous readings were taken by AMOCO using a similar type measuring instrument which was calibrated to read hydrocarbons as percent butane. Their readings were generally lower than our readings since our gascope was calibrated to read in percent methane.

Because of interference with internal structures in certain cargo tanks, we were able to drop the sampling probe to the bottom of only six cargo tanks, before ballasting operations began. Access to each tank was through the 10½ inch diameter ullage gauging opening which was located 40 inches above deck level and atop the tank manhole hatch cover. Measurements recorded from our gascope are presented on data sheets at the end of this report.

Several points worth noting are:

> Higher concentrations were observed in tanks 6C and 10C than in the other tanks sampled. This was because 6C had arrived only half full of crude thereby providing a large vapor space above the crude for light hydrocarbons to evaporate into. Also it was reported that the steam coils in the tank were in poor repair and possibly leaking steam. The reason tank 10C had higher than average hydrocarbon concentrations is that strippings from the bottoms of all the other cargo tanks were pumped to this tank and collected before being pumped ashore.
>
> A hydrocarbon concentration versus depth analysis was run on tank 4C at two times which were separated by

several hours. Data taken prior to ballasting on this tank showed a vapor blanket of about 2-3 feet thick ranging in concentration from 6 to 40 percent. After about 5 or 6 hours another test was made. The tank had been ballasted to a 34 foot ullage by then. The measurements indicated that the blanket was now about 6-7 feet thick ranging in concentration from 7 to 36 percent. Several factors could account for this: (1) initial ballast water inlet agitating and dispensing the vapor blanket in the bottom of the tank, (2) evaporation of volatile hydrocarbons from the crude oil heel left in the tank, and (3) vertical diffusion of these vapors into the empty compartment.

Forty percent of the cargo space was ballasted. This is a larger amount than was expected. Various sources estimate the amount of ballast typically taken on at dock for crude tankers to be 20 to 30 percent.

Ship personnel mentioned that the crude cargo tanks are washed with oil (similar to butterworthing with water) to remove the heavy ends (waxes, paraffins, tars, etc.) which stick to the tank walls. More information about this operation is needed since little detail was obtained during the discussion. Hydrocarbon concentrations in a tank "cleaned" in this manner could increase substantially due to this operation.

- Ballast water was pumped into each tank at a relatively slow rate. Rough calculations indicate the water was pumped in at 2,000-3,000 barrels per hour.

- The M/V Ocean Challenger is classified as a type "A" tanker. For this class of ships the displaced vapors from the cargo tanks can be vented through a manifold system which includes a P/V valve and a flame arrestor at masthead level (approximately 55 feet above deck). All tanks, however, were vented not through this system, but through their ullage measuring hatches during ballasting.

- The residual hydrocarbon concentration in the cargo tanks did not appear to be a function of crude RVP.

B. S.S. AMOCO Virginia

This ship is owned by AMOCO Oil Company, has an American crew and sails under the American Flag. The ship is approximately 20,000 DWT and has 27 cargo tanks - 9 center tanks and 9 port and starboard tanks. The Virginia had just returned from a trip to Wilmington, N.C. and Savannah, Georgia. The return trip took 4 days. The cargo unloaded at those ports was fuel oil (1, 2, 3, and 9 tanks across) and gasoline (4, 5, 6, 7, and 8 across). Deballasting operations were completed at approximately 2:45 a.m.

Points worth noting include:

- A full range of arrival conditions were found in the tanks. Tanks 1, 2, 3 and 4 wings had a less than 1 percent arrival hydrocarbon concentration, tank 5C had a 9 percent concentration, and tanks 7C and 8C had a 20-21 percent concentration. The differences were due to the prior cargo and degree of cleaning each tank had had. Tanks 1, 2, and 3 across had all previously carried a non-volatile product fuel oil. Number 4 port and starboard wing tanks had been gas freed so the crew could enter them for necessary repair work. Tank 5C had carried gasoline on the previous voyage but had been ballasted, vented and washed on the return trip. Tanks 7C and 8C had carried gasoline previously but had been left uncleaned.
- The typical loading sequence used to fill three tanks across with the same product was discussed with one of the mates onboard the Virginia. He said that all three tanks are brought up roughly at the same level until an ullage of 15 to 20 feet is reached in the center tank. Then flow to it is shut off and the two wing tanks are topped off (filled to their final height). After they are finished, loading is resumed into the center tank until it too is topped off. The mate said this sequence is followed for two reasons. It is more difficult to top off three tanks than two and should any problem arise while topping the wing tanks, flow can be easily diverted into the larger center tank until the problem is worked out.

- While talking to the Chief Mate onboard the Virginia, the ballasting of the ship on its return voyage was discussed. He said that the ship is ballasted once at the port that it discharges its cargo, but that it usually dumps this ballast (if over 100 miles from shore) and takes on a fresh ballast. This operation, he explained, cleans the cargo holds and also allows the ship to discharge ballast into port waters rather than return them to the refinery for disposal. This aids the ship in reducing its turnaround time in port since the slop line at most docks can handle only a small discharge rate.

Measurements taken during the loading of the Virginia are presented at the end of this trip report.

V. Conclusions

From observations made during this sampling trip, several conclusions may be drawn.

(1) Factors which cause higher residual hydrocarbon concentrations in crude oil cargo tanks prior to ballasting are: (a) partially loaded tanks; (b) pumping strippings from the ships tanks into a designated tank prior to final unloading causes higher concentrations in that tank; and (c) washing crude cargo tanks with oil.

(2) Based on the data taken onboard the M/V Ocean Challenger, the RVP of the crude oil unloaded has no effect on the residual hydrocarbon concentration of the empty tanks.

(3) Factors which cause higher emission levels for gasoline loading onto a tanker include: (a) prior cargo, (b) extent of cleaning (ballasted once or twice, vented, blown dry, butterworthed, stripped); (c) initial loading rate; (d) product RVP and temperature; (e) ambient temperature; and (f) fill time.

(4) The hydrocarbon emissions from the loading of gasoline onto a tanker can be substantially reduced by ballasting, washing, and venting cargo tanks on the return voyage.

MEASUREMENTS TAKEN ABOARD
M/V OCEAN CHALLENGER AND
SS AMOCO VIRGINIA

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet I
Survey of Shore-Side Information

General Information

Date May 27
Name of vessel Ocean Challenger
Terminal ARCO, Texas City
Product(s) loaded Unleaded, crude oil, [illegible] heating oil [illegible]

Terminal Information

Storage tank number
Storage tank size
Type of roof Floating Roof [illegible]
Length of time stored
Tank color; age ,
Storage temperature
Pump type
Pump size
Pump nominal rate

Ambient Conditions

Air temperature [illegible] 75°F in [illegible] 85°F [illegible]
Weather conditions [illegible]

Prepared by: [illegible]

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet II

Survey of Vessel Information

General Information

Date

Name of vessel [illegible] Challenger

Type of vessel: ship ✓ barge

Total number of cargo tanks 22

Vessel size (DWT) 52,000 DWT

355,905 Bbl.

Prior Cargo Information

Prior cargo Trinidad Crude, Es Sider Crude

Prior cargo RVP Trinidad - 3.8 psia ; Es Sider - [illegible] psia

Where unloaded

Date unloaded

Does cargo tank have stripper lines yes

Vessel In-Transit Conditions

Type cleaning and/or ballasting for each tank

Open or closed hatches

Ratings on PV valve ,

Time at sea

Prepared by:

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet III

Recorded Data

Date May 27

Product Loaded

Cargo Tank No

Loading Rate total rate from simultaneous tanks was 14,000 bbl/hr.

I. Hydrocarbon Profile Prior to Loading

	% LEL	% Gas
Bottom		
Middle		
Top (deck level)		

II. ~~Vapor Blanket Depth~~ Hydrocarbon Profile of empty tank

A. ~~At Lower Level of~~ Tank 6C now empty

upon arrival

Time	Depth ~~Ullage~~ (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)
	55		25		
	50		25		
	45		25		
	40		27		
	35		25		
	30		25		
	25		"		
	20		"		

B. ~~At Upper Level of~~ Tank 4C now empty

Time	Depth ~~Ullage~~ (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)
	55		[illegible]		
	50		[illegible]		
	45		[illegible]		
	35		[illegible]		
	30		[illegible]		
	[illegible]		[illegible]		
	[illegible]				

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet III

Recorded Data

Date Nov. 27
Product Loaded ______
Cargo Tank No ______
Loading Rate total rate from simultaneous tanks was 17,300 bbl/hr

I. **Hydrocarbon Profile Prior to Loading**

	% LEL	% Gas
Bottom		
Middle		
Top (deck level)		

II. ~~Vapor Blanket Depth~~ Hydrocarbon Profile of empty tank

A. ~~At Lower Level of~~ Tank 4C during ballasting

Time	height above level of liquid ~~Ullage~~ (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)
	13"		30		
	23"		37		
	33"		35		
	41"		34		
	51"		16		
	63"		9		
	72"		7		

blanket was at 34' ullage

B. ~~At Upper Level of~~ Tank 3C EMPTY

Time	Depth ~~Ullage~~ (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)
	15'		5		
	35'		5		
	50'		5		
	57'		5		

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet III

Recorded Data

Date [illegible]

Product Loaded

Cargo Tank No

Loading Rate [illegible] tanks [illegible] 14,000 [illegible]

I. Hydrocarbon Profile Prior to Loading

	% LEL	% Gas
Bottom		
Middle		
Top (deck level)		

II. ~~Vapor Blanket Depth~~ Hydrocarbon Profile of empty tanks

A. ~~At [illegible] of~~ Tank 5P EMPTY

Time	Depth ~~Ullage~~ (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)
	[illegible]		[illegible]		
	[illegible]		[illegible]		
	[illegible]		[illegible]		
	[illegible]		[illegible]		
	[illegible]		[illegible]		

B. ~~At Upper Level of Tank~~ 7S EMPTY

Time	Depth Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)
	[illegible]		[illegible]		
	[illegible]		[illegible]		
	[illegible]		[illegible]		

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet III

Recorded Data

Date ____________________ Product Loaded ____________________

Cargo Tank No ____________________ Loading Rate ____________________

I. Hydrocarbon Profile Prior to Loading

	% LEL	% Gas
Bottom		
Middle		
Top (deck level)		

II. ~~Vapor Blanket Depth~~ Hydrocarbon Profile of Empty Tank

A. ~~At Lower Level of~~ Tank [illegible] EMPTY

Time	~~Ullage~~ Depth (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)
	20		.15		
	30		.15		
	35		.22		
	40		.30		
	50		.30		

This tank [illegible]

B. At Upper Level of Tank

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)

FORM MD-8A 11-67

SHIP INNAGE / ULLAGE REPORT

VESSEL M/T OCEAN CHALLENGER VOYAGE NO. 8 DATE May 25th, 1976

PORT Texas city, Texas. TERMINAL No.40

TANK	PORT				CENTER				STARBOARD			
NO.	INNAGE/ULLAGE	BARRELS	W	T	INNAGE/ULLAGE	BARRELS	W	T	INNAGE/ULLAGE	BARRELS	W	T
1	1-49	2688.1	ESSIDER						1-49	2688.1	ESSIDER	
2	3-12	2892.4	TRINIDAD		EMPTY				3-23	2867.9	TRINIDAD	
3	1-50	1690.7	ESSIDER		1-49	3471.9	ESSIDER		1-49	1691.9	ESSIDER	
4	1-53	1687.2	TRINIDAD		1-52	3465.1	ESSIDER		1-53	1687.2	TRINIDAD	
5	1-52	1688.4	TRINIDAD		EMPTY				1-52	1688.4	TRINIDAD	
6	1-49	3383.1	ESSIDER		9-13	1741.4	TRINIDAD		1-49	3383.3	ESSIDER	
7	1-54	3143.0	ESSIDER		1-49	3471.9	TRINIDAD		1-49	3154.4	ESSIDER	
8	↑ ↑				1-43	3485.5	ESSIDER					
9	M CM				1-44	3483.2	ESSIDER					
10					1-09	3557.4	TRINIDAD					
11												
12												

CRUDE ULLAGES AT ARRIVAL

CARGO COMPUTATION

PRODUCT	TANKS	GROSS BARRELS	TEMP.	CORR.	NET BARRELS	A.P.I.	BARRELS PER TON	NET TONS

DRAFT

CARGO:	START	FINISH
Forward		
Aft.		
Mean		
MIDSHIPS		
HOG/SAG		
HOG/SAG ALL*		
Salinity		
F. W. A.		
M. S. W.		

DEADWEIGHT DETERMINATION

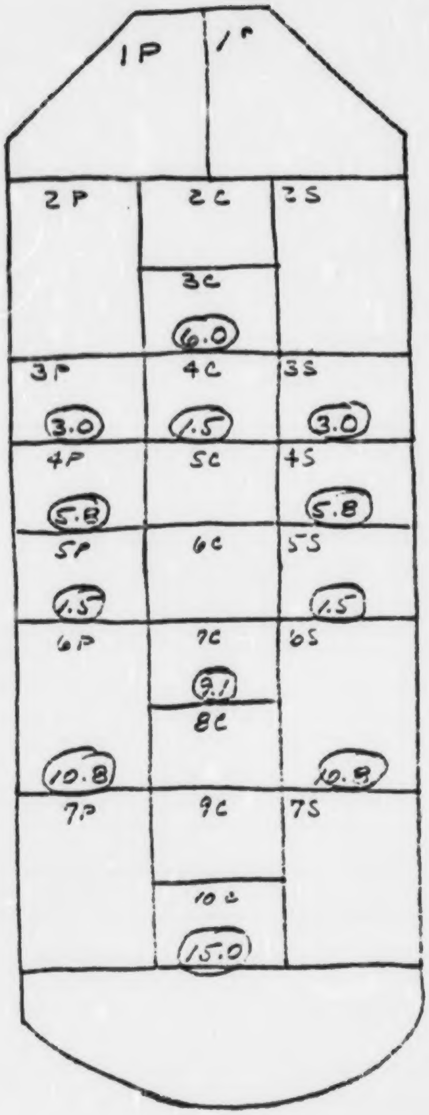
(AFTER LOADING - BEFORE DISCHARGE)

Cargo	
Fuel	
Water	
Stores	
Total	
Allowable Dwt.	
Over/Short	

GUAGER

OFFICER

Note: Hog/Sag Allowance (inches) = 2/3 Hog/Sag (inches)
For Hog, Allowance is subtracted from Draft
For Sag, Allowance is added to Draft


1P
2P
2C
2S
3C
6.0
3P
4C
3S
3.0
1.5
3.0
4P
5C
4S
5.8
5.8
5P
6C
5S
1.5
1.5
6P
7C
6S
9.1
8C
10.8
10.8
7P
9C
7S
10C
15.0

Ballast Pattern
(ullage level in ~~f~~ meters)

40% of ships
capacity ballasted.

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet I

Survey of Shore-Side Information

General Information

Date May 28, 1976
Name of vessel Amoco [illegible]
Terminal Amoco - Texas City
Product(s) loaded Gasoline

Terminal Information

Storage tank number ____________
Storage tank size ____________
Type of roof ____________
Length of time stored ____________
Tank color; age ____________, ____________
Storage temperature ____________
Pump type ____________
Pump size ____________
Pump nominal rate ____________

Ambient Conditions

Air temperature [illegible]
Weather conditions [illegible]

Prepared by: [illegible]

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet II

Survey of Vessel Information

General Information

Date 5/25/7[illegible]
Name of vessel Virginia (Amoco)
Type of vessel: ship ✓ barge
Total number of cargo tanks 27
Vessel size (DWT) 20 DWT

Prior Cargo Information

Prior cargo [illegible] gasoline
Prior cargo RVP [illegible]
Where unloaded Wilmington N.C. and Savannah Georgia
Date unloaded May [illegible]
Does cargo tank have stripper lines yes

Vessel In-Transit Conditions

Type cleaning and/or ballasting for each tank
Open or closed hatches [illegible]
Ratings on PV valve ,
Time at sea [illegible]

Prepared by:

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet III

Recorded Data

Date Mar. 28 Product Loaded Unleaded

Cargo Tank No 3C Loading Rate 5000 BBL/hr

I. Hydrocarbon Profile Prior to Loading

	% LEL	% Gas
Bottom		0
Middle		0
Top (deck level)		0

II. Vapor Blanket Depth

A. At Lower Level of Tank

Probe [illegible] above surface

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)
5:40	42		8	72	
5:47	38		20		
5:54	37		12		
5:55	36		13		
5:56		34	2		

1'
1'
1'
1'
3'

B. At Upper Level of Tank

Time	Liquid Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)
9:30	9'		38	78°	78°
9:50	8'6"		14		
9:51	8'		6		
			5		
			4		

1'
2'
3'
4'
5'

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet III

Recorded Data

Date	[illegible]	Product Loaded	[illegible]
Cargo Tank No	4C	Loading Rate	

I. Hydrocarbon Profile Prior to Loading

	% LEL	% Gas
Bottom		
Middle		
Top (deck level)		

II. Vapor Blanket Depth

A. At Lower Level of Tank

Empty tank

Time	Liquid Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)	Probe height above liquid
6:05	43		17			1'
6:10	43	54	2			3'
6:12	43	35	2			3'
6:15	43	35	2			15'

B. At Upper Level of Tank

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)	Probe height above liquid
9:10	12		37	78°F		1'
9:13	11'6"		32			3'
9:15	11'		13			3'
9:16	11'		3			4'
9:30	10'		49	81°F	80°F	1'
9:3[illegible]			32			3'
[illegible]			13			3'
[illegible]	7'8"		7			[illegible]
[illegible]			9			[illegible]
[illegible]			[illegible]			[illegible]

loading was interrupted

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet III

Recorded Data

Date [illegible] Product Loaded Super Premium

Cargo Tank No 4P Loading Rate [illegible]

I. Hydrocarbon Profile Prior to Loading

	% LEL	% Gas
Bottom		
Middle		
Top (deck level)		

II. Vapor Blanket Depth

A. At Lower Level of Tank

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)
5:15	39'		7	72°F	
5:20	38'		1		
5:25	38'		2	"	
5:30	37'	4		72°F	

Probe height
Above surface
1'
2'
3'
5'

B. At Upper Level of Tank

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)
7:35	17		12%	78	
7:40	[illegible]		21%	78	
7:4[illegible]	[illegible]		4%	[illegible]	

Probe height
Above liquid
1'
2'
3'

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet III

Recorded Data

Date May 28 Product Loaded [illegible]

Cargo Tank No 5C Loading Rate

I. Hydrocarbon Profile Prior to Loading

	% LEL	% Gas
Bottom		9%
Middle		9%
Top (deck level)		9%

II. Vapor Blanket Depth

A. At Lower Level of Tank

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)
4:55	40		26	72	
5:00	39		16	72	
5:04	38		15	72	

Probe height above surface
1'
2'
3'

B. At Upper Level of Tank

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet III

Recorded Data

Date May 28/76　　Product Loaded Super Premium

Cargo Tank No ✓ 2C　　Loading Rate 5000 BPH [illegible]

I. **Hydrocarbon Profile Prior to Loading**

	% LEL	% Gas
Bottom		26
Middle		21
Top (deck level)		21

amb - 82°F

II. **Vapor Blanket Depth**

A. **At Lower Level of Tank**

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)
2:15	43'3"		21	108	
2:20	42		24	112	
2:22	41		25	112	
2:32	40		26	114	
2:40	39		26	110	
2:45	36		26	112	
2:52	37		26	110	
2:55	[illegible]		26	108	
3:05	35		29	108	
3:13	34		37	109	
3:17	33		43	108	

Fixed [illegible]

B. **At Upper Level of Tank**

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)
6:55	17'6"		22	[illegible]	[illegible]
7:00	17'		23	[illegible]	
7:05	[illegible]		[illegible]	[illegible]	
[illegible]	[illegible]		[illegible]	[illegible]	
[illegible]	[illegible]		[illegible]	[illegible]	
[illegible]	[illegible]		[illegible]	[illegible]	
[illegible]	[illegible]		27	[illegible]	
[illegible]	[illegible]		[illegible]	[illegible]	
[illegible]	[illegible]		[illegible]	[illegible]	
[illegible]	[illegible]		[illegible]	[illegible]	
[illegible]	[illegible]		[illegible]	[illegible]	
[illegible]	[illegible]		[illegible]	[illegible]	
[illegible]	[illegible]		[illegible]	[illegible]	
6:10	[illegible]		[illegible]	[illegible]	
[illegible]	[illegible]		[illegible]		

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet III

Recorded Data

Date 4/24 75 Product Loaded Premium

Cargo Tank No 7C Loading Rate

I. Hydrocarbon Profile Prior to Loading

	% LEL	% Gas
Bottom		24
Middle		20
Top (deck level)		20

II. Vapor Blanket Depth

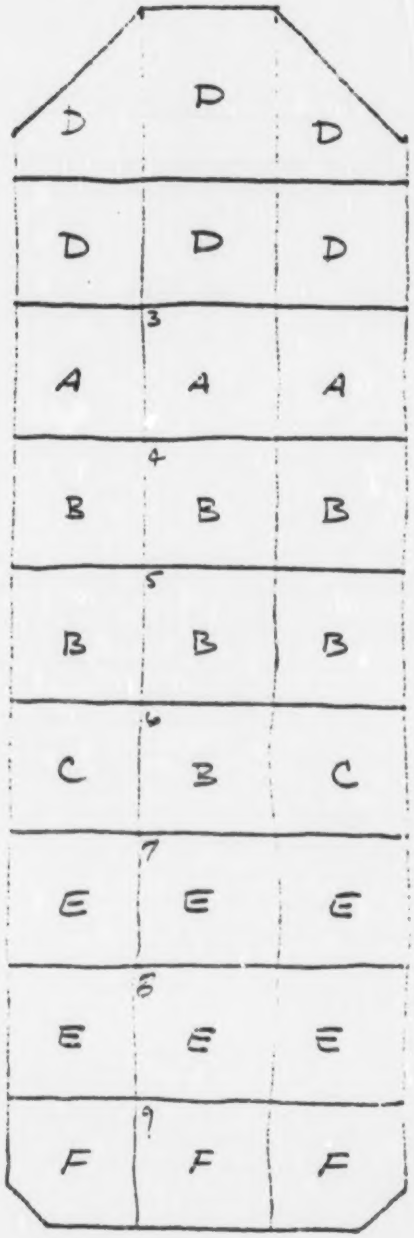
A. At Lower Level of Tank

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)

B. At Upper Level of Tank

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)

Upcoming Trip


D
D
D
D
D
D
3
A
A
A
4
B
B
B
5
B
B
B
6
C
B
C
7
E
E
E
8
E
E
E
9
F
F
F

Loaded at Amoco

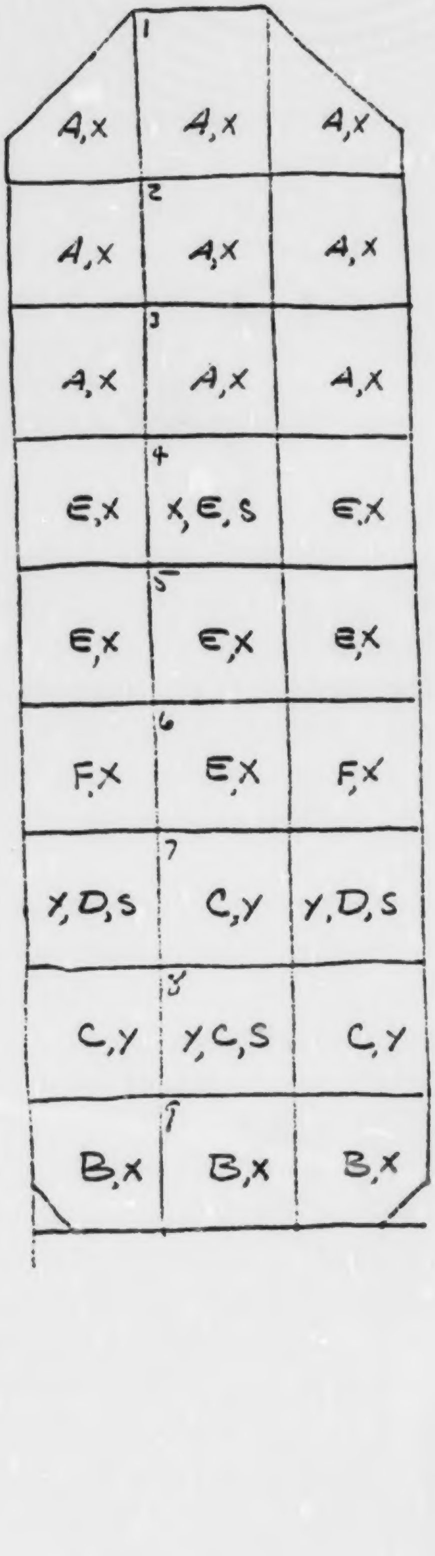
A - Amoco 91 unleade
B - Amoco Super Premiu
C - Empty for Ballast

Loaded at Marathon

D - Amoco 91 unleade
E - leaded Premium
F - Diesel

Amoco Super Premium	11.1
A-91	9.9
Regular	?

Previous Trip



1	A,x	A,x	A,x
2	A,x	A,x	A,x
3	A,x	A,x	A,x
4	E,x	x,E,S	E,x
5	E,x	E,x	E,x
6	F,x	E,x	F,x
7	Y,D,S	C,Y	Y,D,S
8	C,Y	Y,C,S	C,Y
9	B,x	B,x	B,x

A - R.R. Diesel
B - Diesel
C - Amoco Super Premium
D - Amoco 91 unleaded
E - Regular - "house brand"
F - Ballast during trip

S - Split unloadings ≈50% delivered to each port

X washed & vented
Y not washed

SAMPLING TRIP REPORT

Gasoline Loading - Exxon's Port Everglades

On 3 June 1976 David Colley and Clint Burklin visited the Exxon port facilities in Baytown, Texas for the purpose of measuring hydrocarbon emissions during the loading of Exxon's ocean barge; the Port Everglades. The Port Everglades is a barge in that it is pushed by a detachable tugboat, however it is as large as many tankers. Its tanks have 43 ft. ullages, and the barge's size is 30,000 DWT.

The Port Everglades had just returned from a delivery of motor gasoline to Tampa, Florida. Tanks 1 center, 3 port, and 3 starboard were ballasted on the return voyage. The return voyage took 4 to 5 days. None of the empty cargo tanks had been cleaned. Because of limited crew availability, tank cleaning and vapor freeing is not a standard practice on ocean barges.

Products were loaded onto the Port Everglades in much the same manner as tanker loadings. Ballast water was completely discharged prior to taking on products. The ship to shore connection was made with 8"-10" rubber hoses. Three products were loaded simultaneously at individual pumping rates of 10,000 bbl/hr.

The Port Everglades is equipped with automatic ullage gauges, all of which were in good working condition. Each gauge window was equipped with an internal windshield-wiper for removing condensate. These ullage gauges worked well, and were used by the crew for monitoring tank levels. However, each tank was topped of visually by sighting through the ullage caps.

The sampling data taken by Mr. Colley and Mr. Burklin are presented on the following data sheets.

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet I
Survey of Shore-Side Information

General Information

Date June 3, 1976
Name of vessel Exxon Port Everglades
Terminal Exxon Baytown Refining Docks
Product(s) loaded Exxon Extra, Unleaded, and Regular Gasoline

Terminal Information

Storage tank number #818, 816, 731
Storage tank size
Type of roof
Length of time stored
Tank color; age ,
Storage temperature
Pump type
Pump size
Pump nominal rate 10,000 bbl/hr max per pump

Ambient Conditions

Air temperature 75 - 80°F
Weather conditions Windy 10-15 mph

Prepared by: David Colley

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet II

Survey of Vessel Information

General Information

Date June 3, 1976

Name of vessel Exxon Port Everglades

Type of vessel: ~~ship~~ integrated barge/tow ✓

Total number of cargo tanks ✓ 12

Vessel size (DWT) 30,000

Prior Cargo Information

Prior cargo Exxon Regular, Extra, and unleaded Gasoline

Prior cargo RVP

Where unloaded Tampa, Florida

Date unloaded

Does cargo tank have stripper lines yes

Vessel In-Transit Conditions

Type cleaning and/or ballasting for each tank

ballasted tanks 1C and 3 wings

Open or closed hatches

Ratings on PV valve ,

Time at sea

Prepared by: David Colley

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet III

Recorded Data

Date June 3, 1976 Product Loaded

Cargo Tank No Loading Rate

Readings taken 3-4 hrs after deballasting

I. Hydrocarbon Profile Prior to Loading

	% LEL	% Gas
Bottom		
Middle		
Top (deck level)		

II. ~~Vapor Blanket Depth~~ Hydrocarbon Profile Prior to Loading

~~A. At Lower Level of Tank~~ Tank 1C

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)
	5		6		
	15		6		
	22'6"		12		
	25		14		
	27'6"		27		
	30		35		
	35		35		
	44'3"		35		

~~B. At Upper Level of Tank~~ Tank 1S

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)
	5		9		
	10		9		
	20		9		
	30		10		
	40		11		
	43		11		

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet III

Recorded Data

Date June 3, 1976 Product Loaded

Cargo Tank No Loading Rate

Readings Taken 3-4 hrs. after deballasting

I. Hydrocarbon Profile Prior to Loading - Tank 1P

	Ullage (ft)	% LEL	% Gas
Bottom	43	12	
Middle	25	11	
Top (deck level)	5	9	

II. ~~Vapor Blanket Depth~~ Hydrocarbon Profile Prior to Loading

A. ~~At Lower Level of Tank~~ Tank 2C

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)
	5		21		
	15		21		
	30		22		
	43		22		

B. ~~At Upper Level of Tank~~ Tank 2P

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)
	5		21		
	15		22		
	43		22		

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet III

Recorded Data

Date June 3, 1976 Product Loaded ____________

Cargo Tank No ____________ Loading Rate ____________

Readings taken 3-4 hrs after deballasting

I. Hydrocarbon Profile Prior to Loading Tank 3C

	Ullage	% LEL	% Gas
Bottom	43	>100	10
Middle	35	>100	10
	15	>100	10
Top (deck level)	5	>100	10

II. ~~Vapor Blanket Depth~~ Hydrocarbon Profile Prior to Loading

~~A. At Lower Level of Tank~~ Tank 3P

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)
	5	51	2		
	25	58	2		
	35	100	4		
	40	>100	11		
	42	>100	12		

~~B. At Upper Level of Tank~~ Tank 3S

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)
	20	30	1		
	30	>100	3		
	35	>100	4		
	42	>100	7		

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet III

Recorded Data

Date June 3, 1976 Product Loaded ____________

Cargo Tank No ____________ Loading Rate ____________

Readings taken 3-4 hrs after deballasting

I. Hydrocarbon Profile Prior to Loading - Tank 4C

	Ullage (ft)	% LEL	% Gas
Bottom	42		20
Middle	25		20
Top (deck level)	5		20

II. ~~Vapor Blanket Depth~~ Hydrocarbon Profile Prior to Loading

~~A. At Lower Level of Tank~~ Tank 4S

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)
	41		32		
	40		32		
	35		32		
	30		32		
	25		27		
	20		5		
	10	50	2		

~~B. At Upper Level of Tank~~ Tank 4P

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)
	41		41		
	35		38		
	25		36		
	20		34		
	15		15		
	10		10		
	5		6		

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet III

Recorded Data

Date June ~~3~~ 4, 1976 Product Loaded Exxon Regular

Cargo Tank No 1C Loading Rate approx 10,000 bbl/hr

I. **Hydrocarbon Profile Prior to Loading**

	% LEL	% Gas
Bottom		35
Middle		14
Top (deck level)		6

II. **Vapor Blanket Depth**

A. **At Lower Level of Tank** — Fast initial load —

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)	Probe Height ~~Above~~ Above Liquid
0015	42		32	83		12'
0028	40		35	83		10
0033	39		35	82		9
0038	38		35	81		8
0042	37		35	81		7
0049	36		35	80		6
0055	35		35	80		5
0101	34		36	80		4
0106	33		37	80		3
0112	32		45	80		2
0117	31		55	79		1

B. **At Upper Level of Tank**

	Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)	Probe Ht. Above Liquid
	0210	22		12			
	0230	19		14			
Shut off →	0245	18		14			
	0347	16		34			
Shut off →	0354	15		34			
avitated 1ft →							
liquid into 1P correct improper list	0500	16		56			
No flow into tank				50			
				42			
				36			
				35			
				35			

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet III

Recorded Data

Date June 4 1976 Product Loaded Exxon Regular

Cargo Tank No 1S Loading Rate 10,000 bbls/hr

I. Hydrocarbon Profile Prior to Loading

	% LEL	% Gas
Bottom		
Middle		
Top (deck level)		

II. Vapor Blanket Depth

A. At Lower Level of Tank

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)	Probe ft. above liq su
0408	36		10	78		6
0410	35		10			5
0412	34		10			4
0414	33		10			3
0417	32		25			2
0420	31		42			1

B. At Upper Level of Tank

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet III (Cont.)

Recorded Data

Date June 4, 1976

Product Loaded Exxon Unleaded

Cargo Tank No 3S

Loading Rate

III. Hydrocarbon Concentration on Vented Vapors

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T (°F)
	Empty				
	55				
	50				
	45				
	40				
	35				
	30				
0250	16	50	2		
0254	15	54	2		
0255	14	66	2		
0257	13	>100	4		
0300	12		6		
0303	11		8		
0305	10		12		
0307	9		21		
0310	8		47		
0312	7		49		
0315	6		51		
	5				
	4				
	3				
	2				
	1				

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet III

Recorded Data

Date June 4, 1976

Product Loaded Exxon Unleaded

Cargo Tank No 3P

Loading Rate

I. Hydrocarbon Profile Prior to Loading

	Ullage (ft)	% LEL	% Gas
Bottom	42	>100	12
Middle	25	58	2
Top (deck level)	5	51	2

II. Vapor Blanket Depth

A. At Lower Level of Tank

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)

B. At Upper Level of Tank

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)	Probe 4ft. above liquid
0132	19		4	78		9
0135	18		4			8
0138	17		6			7
0142	16		9			6
0145	15		19			5
0147	14		31			4
0149	13		46			3
0152	12		56			2
0154	11		62			1

SAMPLING TRIP REPORT

Gasoline Loading - Exxon Barge No. 119

On 15 June 1976 David Colley and Clint Burklin visited the Exxon port facilities in Baytown, Texas for the purpose of measuring hydrocarbon emissions from the loading of gasoline onto barges.

The Exxon Barge No. 119 is a typical product barge with 6 cargo tanks 12 ft. deep. At the time, E.B. 119 was in dedicated service delivering gasoline to facilities along the Houston Ship Channel. For these gasoline loading tests, the E.B. 119 had returned from unloading gasoline just two hours previously. The short elapse time between unloading and loading operations for EB-119 have potentially lowered its loading emissions.

The sampling data taken by Mr. Colley and Mr. Burklin are presented on the following data sheets.

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet I

Survey of Shore-Side Information

General Information

Date June 15, 1976

Name of vessel Exxon Barge No. 119

Terminal Exxon Baytown Refinery Docks

Product(s) loaded

Terminal Information

Storage tank number

Storage tank size

Type of roof

Length of time stored

Tank color; age ,

Storage temperature

Pump type

Pump size

Pump nominal rate

Ambient Conditions

Air temperature 80°F

Weather conditions Partly cloudy; 10-15 mph wind

Prepared by: David Colley

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet II

Survey of Vessel Information

General Information

Date June 15 1976

Name of vessel Exxon Barge No. 119

Type of vessel: ship ____ barge ✓

Total number of cargo tanks 6 max ullage = 12'

Vessel size (DWT) ____

Prior Cargo Information

Prior cargo Motor Gasoline

Prior cargo RVP ____

Where unloaded Houston, Texas

Date unloaded June 14, 1976

Does cargo tank have stripper lines ____

Vessel In-Transit Conditions

Type cleaning and/or ballasting for each tank ____

no cleaning

Open or closed hatches ____

Ratings on PV valve ____, ____

Time at sea 2 hours

Prepared by: David Colley

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet III

Recorded Data

Date June 15, 1976

Product Loaded

Cargo Tank No 1P

Loading Rate

I. Hydrocarbon Profile Prior to Loading

		% LEL	% Gas
Bottom	12' ullage		4
Middle			
Top (deck level)			

II. Vapor Blanket Depth

A. At Lower Level of Tank

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)

B. At Upper Level of Tank

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T(°F)

RADIAN MARINE TERMINALS TEST PROGRAM

Data Sheet III (Cont.)

Recorded Data

Date June 15, 1976

Cargo Tank No 2P

Product Loaded ______

Loading Rate ______

III. Hydrocarbon Concentration on Vented Vapors

Time	Ullage (ft)	% LEL	% Gas	Vapor T(°F)	Liquid T (°F)
	Empty				
	55				
	50				
	45				
	40				
	35				
	30				
	25				
	20				
	18				
	16				
	14				
0305	~~12~~ 11	>100	6	81	
031[illegible]	10	>100	8	81	
0314	9		10	81	
0328	8		15	80	
0337	7		23	80	
0345	6		34	80	
0350	5		42	80	
0355	4		50	80	
0400	3		53	80	74
	2				
	1				

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APPENDIX VII

INDEPENDENT ANALYSIS OF VAPOR RECOVERY SYSTEM COSTS

INDEPENDENT ANALYSIS OF VAPOR CONTROL SYSTEM COSTS

1.0 INTRODUCTION

In the course of conducting this program to investigate the control of hydrocarbon emissions from marine terminal operations it has become evident that cost is a major issue in evaluating the feasibility of available emission control technology. Vendor and oil company cost estimates differ significantly on the cost to install a safe reliable vapor control system. In an attempt to place these wide cost ranges in perspective, the EPA has contracted Radian to conduct an independent analysis of vapor control system cost data.

Radian's approach to the cost analysis was to prepare a detailed design of each of the marine transfer vapor control systems likely to be installed in the Houston-Galveston area, and to have these designs costed by a cost estimating consultant experienced with the installation of hydrocarbon processing equipment in the Houston-Galveston area.

The two vapor control systems most likely to be installed in the Houston-Galveston area are the refrigeration system and the absorption system. The refrigeration system recovers by condensation at cryogenic temperatures. The absorption system recovers hydrocarbons from marine transfer vapors by absorption into a lean oil. This lean oil is normally a refinery product stream.

Because several sizes, types, and arrangements of equipment may be used to construct vapor control systems, the systems to be costed in this study were separated into basic components or modules which were costed individually. These modules represented the most common sizes and processing configurations expected to be encountered in the Houston-Galveston area. Radian was able to investigate the economic impact of size, equipment selection, and processing configuration by investigating the individual contribution of each module to the total system cost.

The engineering-construction firm selected by Radian Corporation to estimate the cost of marine vapor control systems was Ref-Chem Corporation of Odessa, Texas. Ref-Chem Corporation is widely experienced in the engineering, construction, and maintenance of chemical and petroleum processing units in the Texas Gulf Coast area.

Sections 2.0 and 3.0 of this appendix discuss the design and cost results of a refrigeration vapor recovery system and of an absorption vapor recovery system.

2.0 REFRIGERATION SYSTEMS

2.1 Cost Basis

This section presents the refrigeration unit design which provided the basis for the cost estimates generated by Ref-Chem Corporation.

Refrigeration vapor recovery systems recover hydrocarbons from marine loading vapors by condensation at cryogenic temperatures and at atmospheric pressure. Figure 2.1-1 presents the flow diagram of a typical refrigeration vapor recovery system. For simplification the refrigeration vapor recovery system has been divided into six distinct components termed modules. Module A consists of the equipment required to transfer hydrocarbon vapors collected onboard marine vessels to the shoreside vapor recovery system. This ship-to-shore connection is normally effected by the use of either a large diameter hose or by a marine loading arm. Module B consists of the vapor collection lines which convey hydrocarbon vapors from the ship-to-shore connector to the vapor condenser unit. Module C is the vapor condenser. In the vapor condenser, hydrocarbons and moisture are condensed from the hydrocarbon vapors yielding a purified air stream containing less than 5 volume percent hydrocarbons. Recovered hydrocarbons and water are returned to the refinery. The lines conveying refrigerant brines and fluids from the refrigeration unit to the condenser compose Module D. Module E is the package refrigeration unit which provides the refrigeration capacity for the condensers. Module F comprises all of the utilities required to operate the vapor recovery system.

Each of these vapor recovery system modules has also been separated into several cost cases which address the cost of

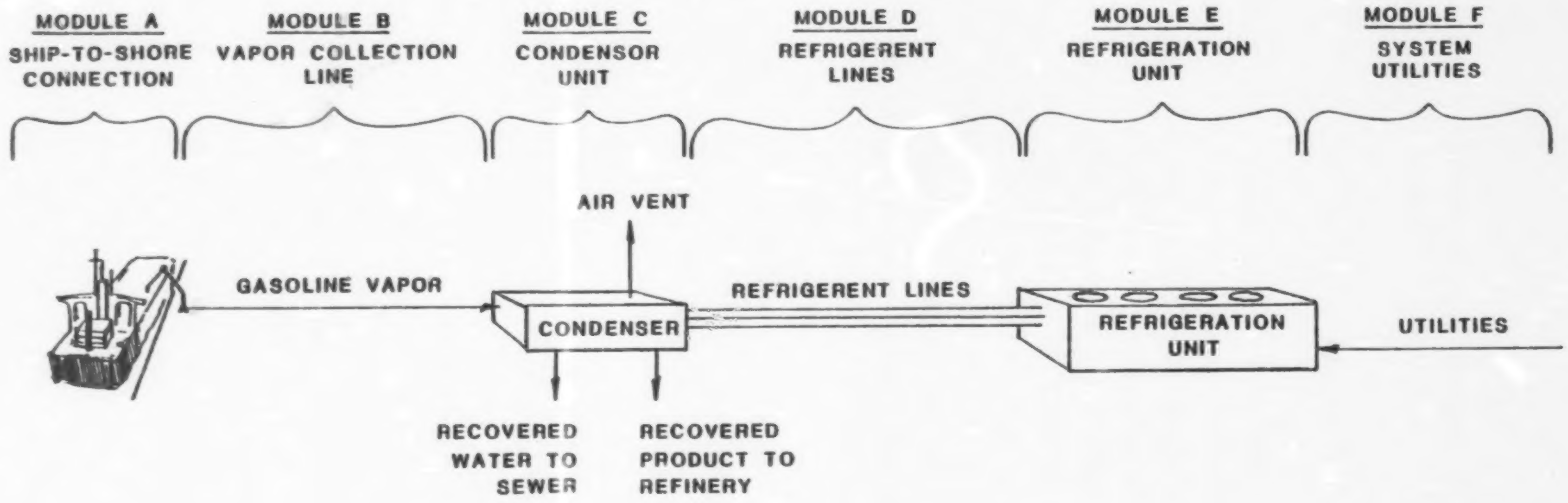
MODULE A
SHIP-TO-SHORE CONNECTION
MODULE B
VAPOR COLLECTION LINE
MODULE C
CONDENSOR UNIT
MODULE D
REFRIGERENT LINES
MODULE E
REFRIGERATION UNIT
MODULE F
SYSTEM UTILITIES
AIR VENT
GASOLINE VAPOR
CONDENSER
REFRIGERENT LINES
REFRIGERATION UNIT
UTILITIES
RECOVERED WATER TO SEWER
RECOVERED PRODUCT TO REFINERY

FIGURE 2.1-1 REFRIGERATION VAPOR RECOVERY SYSTEM

different module sizes or module configurations. These cost cases are characterized by the following module discussions.

Module A: Ship to Shore Connection

Module A consists of the equipment required to transfer hydrocarbon vapors collected onboard marine vessels to shoreside vapor recovery units. In cost cases A1, A2, and A3, a 50 ft. long flexible (yet not collapsible) hose is used for the ship-to-shore connection. The hose is constructed of a gasoline vapor resistant material and terminates on each end with a standard SCH 40 flange. The hoses for cost cases A1, A2, and A3 are sized for ship loading rates of 12,500 bph, 25,000 bph, and 50,000 bph, respectively. The cost of an air driven hoist for hose handling is also included in each of these three cost cases.

Cost cases A4, A5, and A6 are the cases employing a hydraulic-actuated loading arm to achieve the ship-to-shore connection. Loading arms for the three cases are sized for ship loading rates of 12,500 bph, 25,000 bph, and 50,000 bph respectively. The cost cases include the costs associated with construction on crowded existing marine loading docks.

Module B: Vapor Collection Line

Module B investigates the cost of the equipment required to convey hydrocarbon vapors from the ship-to-shore connector (Module A) to the vapor recovery unit (Module C). Cost cases B1, B2, and B3 address the cost of installing short runs of vapor collection piping from the ship-to-shore collector to dock mounted vapor condensers. Pipe fittings, pressure alarms, and safety equipment are included in the cost. The three cases are sized for ship loading rates of 12,500 bph, 25,000 bph, and 50,000 bph, respectively.

Cost cases B4, B5, and B6 address the cost of installing 1000' runs of vapor collection piping from the ship-to-shore connector to centrally-located, shared vapor condensing units. Pipe fittings, pressure alarms, safety equipment, and condensate drains are included in the cost. The three cost cases are sized for ship loading rates of 12,500 bph, 25,000 bph, and 50,000 bph respectively.

Module C: Vapor Condensing Units

Cost case C1, C2, and C3 investigate the cost of installing dock mounted vapor condensing units for ship loading rates of 12,500 bph, 25,000 bph, and 50,000 bph, respectively. Costs include purchase, transportation, and mounting of the units on crowded existing docks. It was assumed that a barge mounted crane was needed for the construction work.

Cost cases C4, C5, and C6 investigate the cost of installing centrally-located, shared condensing units located inland from the docks. These cases are sized for ship loading rates of 12,500 bph, 25,000 bph, and 50,000 bph respectively.

Module D: Refrigeration Lines

Module D investigates the cost of installing refrigerant and defrost fluid piping between the refrigeration unit and the condensation units. The piping materials were selected to withstand exposure to methylene chloride, glycol-water, and trichloroethylene fluids at temperatures down to -100°F. Pipe insulation specifications met the requirements provided by the refrigeration unit manufacturer. Two additional pipelines were included in the Module D design for conveying condensed water from the condenser to the refinery wastewater systems and for conveying condensed hydrocarbons from the condenser to refinery product storage tanks. Cost case D1 represents the cost case for centrally-located, shared condensers and specifies pipe lengths of 100 ft.

Module E: Refrigeration Units

Module E investigates the cost of purchasing and installing the refrigeration units which supply the cooling capacity for the vapor condensers. Costs included in Module E are purchase and transportation of the refrigeration units, preparation of the refrigeration unit site, removal of the units from transport trucks to their foundation, and connection of utilities and piping to the units. The refrigeration unit sites consist of curbed concrete foundations, sidewalks, lighting, fire water supply, and spill drains. Cost cases E1, E2, and E3 represent refrigeration units sized to control ship loading rates of 12,500 bph, 25,000 bph, and 50,000 bph respectively.

Module F: Utilities

Module F comprises several miscellaneous utility items which will be necessary in the installation of a refrigeration vapor recovery system. Cost case F1 addresses the cost required to install sumps, drains, and sewers for the removal of spills, runoff, and wastewater. Process water lines are included in this cost case. The length of the utility lines in Cost case F1 are 3000 ft.

Cost case F2 addresses the cost for expanding the local electrical substation capacity by 2 megawatts. The voltage reduction was assumed to be from 12.8 kv down to 480 v.

2.2 Cost Estimates

Table 2.2-1 presents the cost estimates generated by Radian Corporation for the installation of a completely operable refrigeration vapor recovery system in the Houston-Galveston area. These cost estimates are based on the refrigeration vapor recovery system design basis developed by Radian Corporation which was outlined in Section 2.1. In developing the cost estimates for each cost case, Ref-Chem Corporation considered four cost centers. These cost centers were:

- Direct costs
- Indirect costs
- Contingency allowances
- Contractor fee for overhead and profit

Direct costs include expenditures for labor, materials, equipment and subcontractors used in constructing the various modules. Indirect costs include equipment rentals, consumable supplies, temporary facilities, support labor, and move in - move out. A contingency cost was added to the estimate to provide allowances for cost items not considered elsewhere.

A major cost item not included in the cost estimates is engineering and design. Consultation with several industrial sources indicate that engineering and design work on chemical processing facilities will characteristically cost approximately 10 percent of the construction costs.

TABLE 2.2-1

CONSTRUCTION COST ESTIMATES FOR THE REFRIGERATION VAPOR RECOVERY SYSTEM COMPONENTS (1976)

Item	Cost ($)
Module A: Ship-to-Shore Connection	
Case 1. Rubber hose 12,500 bph	19,000
Case 2. Rubber hose 25,000 bph	20,000
Case 3. Rubber hose 50,000 bph	21,000
Case 4. Loading arm 12,500 bph	68,000
Case 5. Loading arm 25,000 bph	77,000
Case 6. Loading arm 50,000 bph	84,000
Module B: Vapor Collection Line	
Case 1. On the dock condenser 12,500 bph	8,000
Case 2. On the dock condenser 25,000 bph	13,000
Case 3. On the dock condenser 50,000 bph	24,000
Case 4. Central condenser 12,500 bph	96,000
Case 5. Central condenser 25,000 bph	175,000
Case 6. Central condenser 50,000 bph	268,000
Module C: Vapor Condensing Units	
Case 1. Located on the dock 12,500 bph	85,000
Case 2. Located on the dock 25,000 bph	163,000
Case 3. Located on the dock 50,000 bph	324,000
Case 4. Located centrally 12,500 bph	87,000
Case 5. Located centrally 25,000 bph	165,000
Case 6. Located centrally 50,000 bph	324,000
Module D: Refrigerent Lines	
Case 1. On the dock condenser	193,000
Case 2. Central condenser	34,000
Module E: Refrigeration Unit	
Case 1. 12,500 bph	445,000
Case 2. 25,000 bph	839,000
Case 3. 50,000 bph	1,623,000
Module F: Utilities	
Case 1. Water, wastewater, and product lines to the refinery	91,000
Case 2. Electric substation	26,000

2.3 Cost Analysis

The cost of candidate refrigeration vapor recovery system arrangements for construction in the Houston-Galveston area can be analyzed by compiling the appropriate cost estimates for refrigeration system modules presented in Section 2.2. Table 2.3-1 presents the construction costs for five candidate refrigeration systems. A comparison of the costs for System I and for System II indicate that the impact of minor equipment substitutions such as the use of rubber loading hoses instead of automatic loading arms has very little overall impact on the total cost for a refrigeration vapor recovery system. In addition, a comparison of costs for individual dock mounted condensers (System I) and costs for centrally located common condensers (System III) indicate that the individual condensers are approximately 10% more expensive. It has been suggested that individual condensers are much safer than common condensers.

Table 2.3-2 compares the cost of five potential refrigeration systems on a relative size basis. As expected, the costs for larger vapor recovery systems are lower on a unit capacity basis than the costs for smaller systems. The 12,500 bph system is projected to cost $806,000 per 10,000 bph and the 50,000 bph system is projected to cost $775,000 per 10,000 bph. However, the estimated cost range between the least expensive and most expensive refrigeration vapor recovery system applicable to the Houston-Galveston area on a capacity basis is approximately 10%. The cost of all of these systems can be approximated as $800,000 per 10,000 bph of capacity.

TABLE 2.3-1
COMPARISON OF COSTS FOR REFRIGERATION VAPOR RECOVERY SYSTEMS

System I: Two individual dock located condensers with a capacity of 25,000 bph each and a central refrigeration unit with a capacity of 25,000 bph. Automatic loading arms.

Item	Unit Cost	No.	Cost
A-5	77,000	2	154,000
B-2	13,000	2	26,000
C-2	163,000	2	326,000
D-1	193,000	2	386,000
E-2	839,000	1	839,000
F-1	91,000	1	91,000
F-2	26,000	1	26,000
		TOTAL LESS ENGINEERING	1,848,000
		GRAND TOTAL	$2,033,000

System II: A 25,000 bph system with individual dock condensers identical to System I except for the use of rubber hoses on the ship-to-shore connection.

TABLE 2.3-1 (cont'd.) COMPARISON OF COSTS FOR REFRIGERATION VAPOR RECOVERY SYSTEMS

Item	Unit Cost	No.	Cost
A-2	20,000	2	40,000
B-2	13,000	2	26,000
C-2	163,000	2	326,000
D-1	193,000	2	386,000
E-2	839,000	1	839,000
F-1	91,000	1	91,000
F-2	26,000	1	26,000
	TOTAL LESS ENGINEERING		1,734,000
	GRAND TOTAL		$1,907,000

System III: Central 25,000 bph condenser and refrigeration unit servicing two docks. Automatic loading arms.

Item	Unit Cost	No.	Cost
A-5	77,000	2	154,000
B-5	175,000	2	350,000
C-5	165,000	1	165,000
D-2	34,000	1	34,000
E-2	839,000	1	839,000

TABLE 2.3-1 (cont'd.) COMPARISON OF COSTS FOR REFRIGERATION VAPOR RECOVERY SYSTEMS

F-1	91,000	1	91,000
F-2	26,000	1	26,000
		TOTAL LESS ENGINEERING	1,659,000
		GRAND TOTAL	$1,825,000

System IV: Four individual dock located condensers with a capacity of 25,000 bph each and a central refrigeration unit with a capacity of 50,000 bph. Automatic loading arms

Item	Unit Cost	No.	Cost
A-5	77,000	4	308,000
B-2	13,000	4	52,000
C-2	163,000	4	652,000
D-1	193,000	4	772,000
E-3	1,623,000	1	1,623,000
F-1	91,000	1	91,000
F-2	26,000	1	26,000
		TOTAL LESS ENGINEERING	3,524,000
		GRAND TOTAL	$3,876,000

TABLE 2.3-2

SUMMARY OF EXAMPLE REFRIGERATION VAPOR RECOVERY SYSTEM COSTS

System	Cost $	Capacity bph	Relative Cost $/10,000 bbl
System I	2,033,000	25,000	813,000
System II	1,907,000	25,000	763,000
System III	1,825,000	25,000	730,000
System IV	3,876,000	50,000	775,000
System V	1,008,000	12,500	806,000

3.0 ABSORPTION SYSTEMS

3.1 Cost Basis

This section presents the absorption unit design which provided the basis for the cost estimates generated by Ref-Chem Corporation.

Absorption vapor recovery systems remove hydrocarbon vapors from marine loading vapors by absorbing the hydrocarbons into a lean oil stream. The system selected by Radian Corporation for detailed cost analysis utilizes a tray absorber for the oil/vapor contactor. The system operates at near atmospheric pressure and boosts the lean oil absorptivity by chilling the lean oil to 40°F. Figure 3.1-1 presents the flow diagram of an absorption vapor recovery system.

For simplification the absorption vapor recovery system has been divided into eight distinct components termed modules. Module A consists of the equipment required to transfer hydrocarbon vapors collected onboard marine vessels to the shoreside vapor recovery system. This ship-to-shore connection is normally effected by use of either a large diameter hose or by a marine loading arm. Module B consists of the vapor collection lines which convey hydrocarbon vapors from the ship-to-shore connector to the vapor absorption column. The lean oil absorber and directly associated equipment compose Module C. Module D consists of the piping, valves, and pumps required to transport lean oil from the refinery storage area to the vapor recovery system. Module E is the refrigeration unit which is used to chill the lean oil prior to its introduction to the absorber. The air eductor and associated air compression equipment required to draw ship loading vapors through the absorber compose Module F. Module G comprises the piping, valves, and pumps used to return rich oil effluent from the absorber to the refinery product blending area. Module H comprises all of the utilities required to operate the vapor recovery system.

Each of the vapor recovery system modules has also been separated into several cost cases which address the cost of different module sizes or configurations. These cost cases are characterized in the following module discussions.

Module A: Ship-to-Shore Connection

Module A consists of the equipment required to transfer hydrocarbon vapors collected onboard marine vessels to shoreside vapor recovery units. In cost cases A1, A2, and A3, a 50 ft long flexible (yet not collapsible) hose is used for the ship-to-shore connection. The hose is constructed of a gasoline vapor resistant material and terminates on each end with a standard SCH 40 flange. The hoses for cost cases A1, A2, and A3 are sized for ship loading rates of 12,500 bph, 25,000 bph, and 50,000 bph respectively. The cost of an air driven hoist for hose handling is also included in each of these three cost cases.

Cost cases A4, A5, and A6 are the cases employing a hydraulic-actuated loading arm to achieve the ship-to-shore connection. Loading arms for the three cases are sized for ship loading rates of 12,500 bph, 25,000 bph, and 50,000 bph, respectively. The cost cases include the costs associated with construction on crowded existing marine loading docks.

Module B: Vapor Collection Lines

Module B investigates the cost of the equipment required to convey hydrocarbon vapors from the ship-to-shore connector (Module A) to the vapor recovery unit (Module C). Cost cases

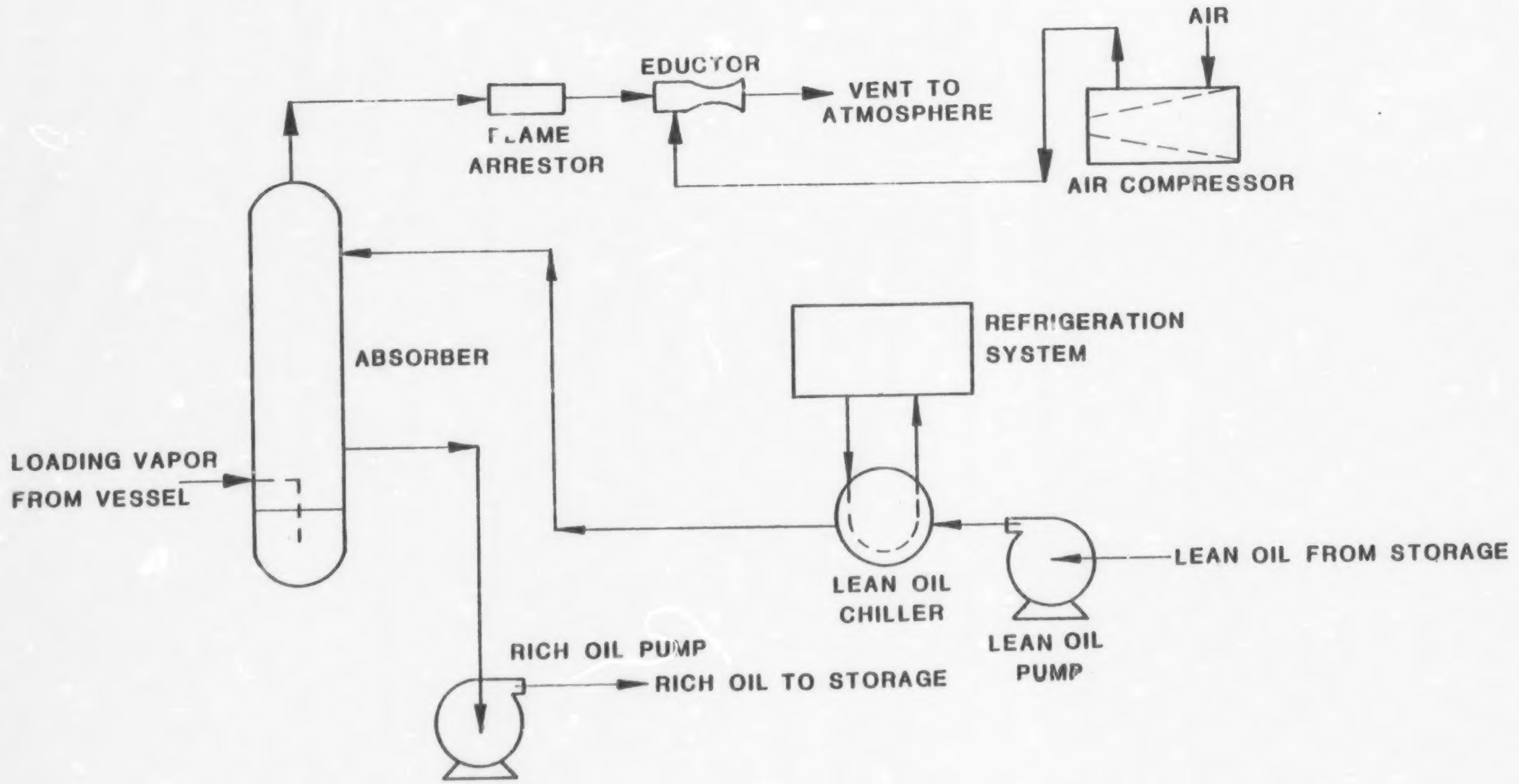
EDUCTOR
VENT TO
ATMOSPHERE
AIR
FLAME
ARRESTOR
AIR COMPRESSOR
ABSORBER
REFRIGERATION
SYSTEM
LOADING VAPOR
FROM VESSEL
LEAN OIL FROM STORAGE
LEAN OIL
CHILLER
LEAN OIL
PUMP
RICH OIL PUMP
RICH OIL TO STORAGE

FIGURE 3.1-1 FLOW DIAGRAM FOR PROPOSED ABSORPTION VAPOR RECOVERY SYSTEM

B1, B2, and B3 address the cost of installing short runs of vapor collection piping from the ship-to-shore collector to dock mounted vapor absorbers. Pipe fittings, pressure alarms, and safety equipment are included in the cost. The three cases are sized for ship loading rates of 12,500 bph, 25,000 bph, and 50,000 bph, respectively.

Cost cases B4, B5, and B6 address the cost of installing 1000 ft runs of vapor collection piping from the ship-to-shore connector to centrally-located, shared vapor absorber units. Pipe fittings, pressure alarms, safety equipment and condensate drains are included in the cost. The three cost cases are sized for ship loading rates of 12,500 bph, 25,000 bph, and 50,000 bph, respectively.

Module C: Lean Oil Absorber

The lean oil absorber is a valve tray tower fabricated out of carbon steel and equipped with a water seal below the bottom tray. The absorber control system regulates lean oil flow rates and tower pressure from inputs including effluent hydrocarbon concentrations, tower temperature profiles, and tower pressure. An automatic N_2 purge system is also associated with the absorber for purging the tower and vapor collection lines after each ship loading operation. Auxiliary piping for Module C includes a water purge line for the absorber water seal and a waste water drain for the water seal overflow. Cost cases C1, C2, and C3 address the cost for installing absorber towers and associated equipment sized to control loading rates of 12,500 bph, 25,000 bph, and 50,000 bph, respectively.

Module D: Lean Oil Piping

Module D consists of the piping, valves, and pump required to transfer lean oil from the refinery storage area to the absorber. Although the refrigeration system employed to chill the lean oil is positioned along this piping, it has been established as Module E. Cost cases D1, D2, and D3 address the cost for constructing long lengths of insulated piping required to transfer chilled lean oil from a central refrigeration unit to individual dock mounted absorbers. These three cost cases are sized to control ship loading rates of 12,500 bph, 25,000 bph, and 50,000 bph, respectively. Cost cases D4, D5, and D6 address the cost of lean oil piping from the refinery to a central absorber located adjacent to the central refrigeration unit. These three cost cases are sized to control ship loading rates of 12,500 bph, 25,000 bph, and 50,000 bph, respectively.

Module E: Refrigeration Unit

The refrigeration unit used to chill the lean oil to 40°F prior to contacting gasoline vapors in the absorber comprises Module E. Heat exchangers, refrigeration units, and a temperature recorder-controller system are included in the lean oil refrigeration unit. Cost cases E1, E2, and E3 address the cost of refrigeration units sized to control ship loading rates of 12,500 bph, 25,000 bph, and 50,000 bph, respectively.

Module F: Compressor-Eductor System

Module F contains the equipment used to motivate gasoline vapors collected onboard the ship through the vapor control equipment. An air eductor provides the motive force using compressed air from a dedicated system. The vacuum at the suction of the eductor is approximately -40 inches of water. An air compressor, air cooler, and air supply lines are also included in Module F. The discharge pressure of the air compressor is 50 psia. Cost cases F1, F2, and F3 represent the construction cost for compressor-eductor systems on dock-loaded absorbers with ship loading capacities of 12,500 bph, 25,000 bph, and 50,000 bph. Cost cases F4, F5, and F6 represent the construction costs for compressor-eductor systems on centrally-located common absorbers with ship loading capacities of 12,500 bph, 25,000 bph, and 50,000 bph. The air compressors for all of the cost cases are centrally located adjacent to the refrigeration system. However, Cost cases F1, F2, and F3 require long air supply lines and greater air compressor capacity to supply compressed air to the distant dock located eductors. Eductors in Cost cases F4, F5, and F6 are located adjacent to the compressor.

Module G: Rich Oil Piping

Module G consists of the piping, valves, and pumps used to transfer rich oil from the absorber to the refinery blending and storage area. Also included in the rich oil piping system is a system for injection of an anti-oxidant into the rich oil stream to inhibit any oxidation of the oil by absorbed air. The rich oil pumping rate is controlled by a level controller in the bottom of the absorption column. Cost cases G1, G2, and G3 estimate the cost of rich oil piping systems which return rich oil to the refinery from distant dock located absorbers sized for ship loading rates of 12,500 bph, 25,000 bph, and 50,000 bph, respectively. Cost cases G4, G5, and G6 estimate the cost of rich oil piping systems which return rich oil to the refinery from centrally located, shared absorbers of the same capacity.

Module H: Utilities

Module H consists of the utility connections required for the operation of the absorption system. These utilities include electricity and instrument air. Cost cases H1, H2, and H3 address the cost of utility systems sized to control ship loading rates of 12,500 bph, 25,000 bph, and 50,000 bph, respectively.

3.2 Cost Estimates

Table 3.2-1 presents the cost estimates generated by Ref-Chem Corporation for the installation of a completely operable absorption vapor recovery system in the Houston-Galveston area. These cost estimates are based on the absorption vapor recovery system design basis developed by Radian Corporation which was outlined in Section 3.1. In developing the cost estimates for each cost case, Ref-Chem Corporation considered four cost centers. These cost centers were:

- Direct costs
- Indirect costs
- Contingency allowances
- Contractors' fee for overhead and profit

Direct costs include expenditures for labor, materials, equipment, and subcontractors used in constructing the various modules. Indirect costs include equipment rentals, consumable supplies, temporary facilities, support labor, and move in - move out. Contingency cost was added to the estimate to provide allowances for cost items not considered elsewhere.

A major cost item not included in the cost estimates is engineering and design. Consultation with several industrial

TABLE 3.2-1

CONSTRUCTION COST ESTIMATES FOR THE ABSORPTION VAPOR RECOVERY SYSTEM COMPONENTS (1976)

Item			Cost $
Module A:	Ship to Shore Connection		
Case 1.	Rubber Hose	12,500 bph	19,000
Case 2.	Rubber Hose	25,000 bph	20,000
Case 3.	Rubber Hose	50,000 bph	21,000
Case 4.	Loading Arm	12,500 bph	68,000
Case 5.	Loading Arm	25,000 bph	77,000
Case 6.	Loading Arm	50,000 bph	84,000
Module B:	Vapor Collection Line		
Case 1.	On the Dock Absorber	12,500 bph	8,000
Case 2.	On the Dock Absorber	25,000 bph	13,000
Case 3.	On the Dock Absorber	50,000 bph	24,000
Case 4.	Central Absorber	12,500 bph	85,000
Case 5.	Central Absorber	25,000 bph	158,000
Case 6.	Central Absorber	50,000 bph	245,000
Module C.	Lean Oil Absorber		
Case 1.	12,500 bph Capacity		48,000
Case 2.	25,000 bph Capacity		60,000
Case 3.	50,000 bph Capacity		66,000
Module D:	Lean Oil Piping		
Case 1.	On the Dock Absorber	12,500 bph	30,000
Case 2.	On the Dock Absorber	25,000 bph	44,000
Case 3.	On the Dock Absorber	50,000 bph	64,000
Case 4.	Central Absorber	13,500 bph	15,000
Case 5.	Central Absorber	25,000 bph	23,000
Case 6.	Central Absorber	50,000 bph	33,000

TABLE 3.2-1 (cont'd.) CONSTRUCTION COST ESTIMATES FOR THE ABSORPTION VAPOR RECOVERY SYSTEM COMPONENTS (1976)

Item		Cost $
Module E. Refrigeration Unit		
Case 1. 12,500 bph Capacity		84,000
Case 2. 25,000 bph Capacity		165,000
Case 3. 50,000 bph Capacity		302,000
Module F. Vacuum Assist Unit		
Case 1. On the Dock Absorber	12,500 bph	92,000
Case 2. On the Dock Absorber	25,000 bph	129,000
Case 3. On the Dock Absorber	50,000 bph	177,000
Case 4. Central Absorber	12,500 bph	71,000
Case 5. Central Absorber	25,000 bph	101,000
Case 6. Central Absorber	50,000 bph	140,000
Module G. Rich Oil Return to Refinery		
Case 1. On the Dock Absorber	12,500 bph	30,000
Case 2. On the Dock Absorber	25,000 bph	43,000
Case 3. On the Dock Absorber	50,000 bph	64,000
Case 4. Central Absorber	12,500 bph	19,000
Case 5. Central Absorber	25,000 bph	27,000
Case 6. Central Absorber	50,000 bph	37,000
Module H. Utilities		
Case 1. 12,500 bph System		18,000
Case 2. 25,000 bph System		24,000
Case 3. 50,000 bph System		29,000

sources indicate that engineering and design work on chemical processing facilities will characteristically cost approximately 10 percent of the construction costs.

3.3 Cost Analysis

The cost of candidate lean oil absorption vapor recovery system arrangements for construction in the Houston-Galveston area can be analyzed by compiling the appropriate cost estimates for absorption system modules presented in Section 3.2. Table 3.3-1 presents the construction costs for four candidate absorption systems. A comparison of the costs for System 1 and System II indicate that the cost of constructing individual absorbers on each dock is not appreciably higher than the cost of constructing central shared absorbers. The cost difference is approximately 5% of the total construction cost. Individual absorbers are considered much safer than common absorbers because they isolate one vessel from another.

Table 3.3-2 summarizes the cost differences between several absorption systems relative to system capacity. Comparison of Systems I, III, and IV indicate that the cost of absorption systems per unit capacity does not differ significantly between 12,500 bph capacity units and 50,000 bph capacity units. The economic impact of absorption systems is similar for both the smaller and the larger installations. The construction cost for the design basis absorption systems studied in the program total approximately $400,000 per 10,000 bph vessel loading capacity.

The data presented in Tables 3.3-1 and 3.3-2 indicate that the cost of absorption units is approximately 50 percent of the cost of refrigeration units. However, the absorption unit design basis developed by Radian Corporation assumed that a large

TABLE 3.3-1
COMPARISON OF COSTS FOR ABSORPTION VAPOR RECOVERY SYSTEMS

System I: Two individual dock located absorbers with a capacity of 25,000 bph each and a central refrigeration and vacuum system with a capacity of 25,000 bph. Automatic loading arms.

Item	Unit Cost	No.	Cost
A-5	77,000	2	154,000
B-2	13,000	2	26,000
C-2	60,000	2	120,000
D-2	44,000	2	88,000
E-2	165,000	1	165,000
F-2	129,000	2	258,000
G-2	43,000	2	86,000
H-2	24,000	1	24,000
		TOTAL LESS ENGINEERING	921,000
		GRAND TOTAL	$1,013,000

System II: Central absorber and refrigeration system each with a capacity of 25,000 bph.

Item	Unit Cost	No.	Cost
A-5	77,000	2	154,000
B-5	158,000	2	316,000
C-2	60,000	1	60,000
D-5	23,000	1	23,000
E-2	165,000	1	165,000

TABLE 3.3-1 COMPARISON OF COSTS FOR ABSORPTION VAPOR RECOVERY SYSTEMS (cont'd.)

F-5	101,000	1	101,000
G-5	27,000	1	27,000
H-2	24,000	1	24,000
		TOTAL LESS ENGINEERING	$870,000
		GRAND TOTAL	$957,000

System III: Four individual dock located absorbers with a capacity of 25,000 bph each and a central refrigeration and vacuum system with a capacity of 50,000 bph.

Item	Unit Cost	No.	Cost
A-5	77,000	4	308,000
B-2	13,000	4	52,000
C-2	60,000	4	240,000
D-2	44,000	4	176,000
E-6	302,000	1	302,000
F-2	129,000	4	516,000
G-2	43,000	4	172,000
H-3	29,000	1	29,000
		TOTAL LESS ENGINEERING	$1,795,000
		GRAND TOTAL	$1,975,000

TABLE 3.3-1 COMPARISON OF COSTS FOR ABSORPTION VAPOR RECOVERY SYSTEMS (cont'd.)

System IV: One 12,500 bph absorber located on the dock with a centrally located 12,500 bph refrigeration and vacuum system.

Item	Unit Cost	No.	Cost
A-4	68,000	1	68,000
B-1	8,000	1	8,000
C-1	48,000	1	48,000
D-1	30,000	1	30,000
E-1	84,000	1	84,000
F-1	92,000	1	92,000
G-1	30,000	1	30,000
H-1	18,000	1	18,000
		TOTAL LESS ENGINEERING	$378,000
		GRAND TOTAL	$416,000

TABLE 3.3-2

SUMMARY OF EXAMPLE ABSORPTION VAPOR RECOVERY SYSTEM COSTS

System	Cost ($)	Capacity (bph)	Relative Cost $/10,000 bbl
System I	1,013,000	25,000	405,000
System II	957,000	25,000	383,000
System III	1,975,000	50,000	395,000
System IV	416,000	12,500	333,000

lean oil supply source was available within the refinery. The lean oil rate required by the design basis absorption system is 125 gpm per 10,000 bph loading rate. A loading operation which involves loading two tankers at a combined loading rate of 50,000 bph will require a lean oil flow rate of 600 gpm. The logistics of deferring such a major portion of a refinery's lean oil production to the absorption system is a significant operation change and is likely to be considered impractical. Without system modifications, the design basis absorption system is primarily applicable to small marine operations at large refineries where the lean oil demand of the absorption system is small relative to the refinery lean oil production rate.

A system modification which would make larger absorption systems compatible with refinery operations is the addition of lean oil storage capacity dedicated for use in the vapor recovery system. This lean oil storage capacity can be filled and emptied at the refinery convenience with minimal disruption of normal operations. Storage capacity costs are approximately $0.15 per gallon. A 100,000 bbl storage tank installed with associated equipment will cost approximately $600,000. The cost of lean oil storage capacity will very likely place the cost of lean oil absorption systems in the same range as the cost for refrigeration systems: approximately $800,000 per 10,000 bph of marine loading capacity.

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